

982-043

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PREDICTING TRAVEL VOLUMES FOR HOV PRIORITY TECHNIQUES

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Technical Report
April 1982
Final Report



Prepared for



US Department of Transportation
Federal Highway Administration

Offices of Research & Development
Traffic Systems Division
Washington, D.C. 20590

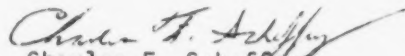
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FOREWORD

This report will be of interest to researchers who are involved in developing forecasting models for changes in urban transportation systems. A review of existing mode split models was made for predicting changes resulting from implementing priority techniques for high occupancy vehicles (HOV's). Data was obtained from several HOV projects in the United States, and a new, simple-to-use forecasting procedure was developed using demand and supply relationships from the HOV data collected. The new model was tested and compared to the Pivot Point Logit Model which has been the most commonly used model to date.

This report is from a contractual effort as part of FCP Project 2D "Priority Techniques for High Occupancy Vehicles." A User's Guide was also prepared as part of this contract which presents the procedure developed, step-by-step with examples.

Copies of this report are being distributed to provide two copies to each regional office, one copy to each division office and one copy to each State highway agency. The division and State copies are being sent directly to each division office.


Charles F. Scheffey
Director, Office of Research

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1. Report No. FHWA/RD-82/043	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle PREDICTING TRAVEL VOLUMES FOR HOV PRIORITY TECHNIQUES: TECHNICAL REPORT		5. Report Date April 1982	
		6. Performing Organization Code	
7. Author(s)		8. Performing Organization Report No. 511.00	
9. Performing Organization Name and Address Charles River Associates Incorporated 200 Clarendon Street Boston, Massachusetts 02116		10. Work Unit No. (TRAIS) 32D4-594	
		11. Contract or Grant No. DTFH61-80-C-00018	
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Research Traffic Systems Division Washington, D.C. 20590		13. Type of Report and Period Covered Final Report January 1980-November 1981	
		14. Sponsoring Agency Code T-0460	
15. Supplementary Notes FHWA Contract Manager: Howard H. Bissell (HRS-33)			
16. Abstract This report describes the research that was undertaken to develop a simple-to-use forecasting procedure for predicting the changes in modal volumes that result from implementing various types of freeway preferential lane projects for buses and/or carpools. First, the results of a review and assessment of existing travel forecasting models are presented. Next, a survey conducted to determine the availability of before and after data from the many high occupancy vehicle (HOV) projects that have been implemented in the United States is described. The relevant data sets that were obtained and used in the analysis are presented. Based on the data that were available, demand and supply relationships were developed and incorporated into a set of worksheets for applying the new forecasting procedure. Tests of forecasts obtained by using the worksheets and an existing Pivot Point Logit Model are described and evaluated. The worksheets that were developed, and a description of their use, is presented in an accompanying User's Guide (FHWA/RD-82-042).			
17. Key Words HOV, High Occupancy Vehicle, Forecasting Sketch Planning, Travel Volumes, Priority Techniques, Bus/Carpool, Transportation Systems Management		18. Distribution Statement No Restrictions. This document is avail- able to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) unclassified	20. Security Classif. (of this page) unclassified	21. No. of Pages 82	22. Price

PREFACE

The work performed during the course of this study is presented in two reports. The first is a "User's Guide" that provides a step-by-step description explaining how the model and worksheets are used to forecast travel volumes. Example applications are also presented. The second report is a "Technical Supplement" that provides a complete documentation of all work tasks conducted. In particular, this report presents much of the underlying data and other information used in the model estimation and testing phases of the study.

The project manager for this study and the principal author of this report was Thomas E. Parody. The computer work was performed by Robert Hirschey, with econometric advice provided by Lawrence Kolbe. Joan Solomon was involved in the initial data collection tasks. Useful oversight and direction were provided by Daniel Brand, with earlier assistance provided by William Tye and Fred Dunbar. Professor Adolf D. May of the University of California at Berkeley contributed important input at various points throughout the course of this study. Finally, the authors would like to thank the many individuals and agencies who cooperated with our requests for information on HOV projects that have been implemented throughout the United States.

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INTRODUCTION

STUDY OBJECTIVE

This report describes the results of a study that was performed to develop and test a travel forecasting procedure to predict travel volumes due to the implementation of priority treatments for high occupancy vehicles (HOV) on freeways. The travel procedures developed and described in this final report are specifically designed to be implementable in the face of severe constraints on turnaround time, data availability, and computational resources, while at the same time providing information that is both accurate and easy to obtain. To meet this quick-response capability, forecasts of peak hour volumes (i.e., for nonpriority automobiles, carpools, and bus transit) are derived by using a common hand-held calculator and an accompanying set of worksheets. Thus, computer facilities are not required.

A comprehensive review of current forecasting procedures that might fulfill the study objective revealed that no existing travel demand models have been estimated using actual before-and-after data from the broad cross-section of HOV demonstrations and projects supported by the U.S. Department of Transportation over the preceding 10 years. Consequently, a new model formulation was proposed and subsequently estimated in this study using empirical before-and-after data from HOV sites across the United States.

The initial plan was to develop one or more models that could be used to evaluate any one of six freeway or arterial HOV treatments. The treatments

for freeways consisted of: 1) separate carpool/bus roadways; 2) restricted carpool/bus lanes withflow and contraflow; and 3) carpool/bus ramp meter bypasses. The HOV treatments for arterials consisted of: 1) withflow carpool/bus restricted lanes; 2) contraflow restricted bus lanes; and 3) reversible carpool/bus lanes. However, after a thorough examination of the data available, it was determined that models could only be estimated for freeway-based HOV sites. Consequently, travel forecasting procedures were developed to analyze the following four HOV freeway strategies:

- Dedicate a new or existing lane for bus-only HOV operation;
- Dedicate a new or existing lane for bus and carpool operation;
- Allow carpools onto an existing bus-only HOV lane; and
- Allow carpools with lower occupancy levels onto an existing bus and carpool HOV lane.

The principal sources examined to obtain before-and-after data consisted of evaluation reports of HOV demonstrations that have been implemented in the past 10 years. The first of these large-scale demonstrations began in 1970 with the announcement of the Urban Corridor Demonstration Program. This program was directed at reducing commuter corridor congestion through the implementation of projects that encourage transit or carpool ridership (e.g., reserved HOV lanes), or that increase the efficiency of existing street systems.* Later, in 1974, FHWA established Research Project 2D, entitled "Priority Techniques for High Occupancy Vehicles," as part of its Federally Coordinated Program (FCP). The objective of the 2D Project was to increase the people moving efficiency of the highway system by: 1) applying a variety of techniques for the preferential treatment of high occupancy vehicles (buses, vanpools, carpools); 2) thoroughly evaluating these techniques with respect to benefits, costs, environmental impacts, and institutional and public acceptance; and 3) providing all information necessary to facilitate wider implementation of the most promising techniques.** Other related FCP projects include: 2K, "Metropolitan Multimodal Traffic Management"; 2M, "Arterial Flow and Control"; and most recently, 2P, "Improved Utilization of Available Freeway Lanes."

Finally, in 1974 UMTA began the Service and Methods Demonstration (SMD) Program to provide a consistent and comprehensive framework within which to formulate, implement, evaluate, and disseminate results of demonstrations

* U.S. Department of Transportation, Urban Corridor Demonstration Program. (Washington, D.C.: DOT P6500.1, October 1974).

**M.J. Rothenberg, Priority Treatment for High Occupancy Vehicles: Project Status Report. (Washington, D.C.: FHWA, March 1977).

including, among other techniques, HOV strategies.* From the results of the many demonstrations sponsored by these programs, there exists a large body of quasi-experimental observations concerning the impacts of different HOV alternatives. These projects represent a prime source of data that, to date, have not been used in a comprehensive manner either to validate the efficacy of existing travel demand models or to develop new models for the prediction of travel flows resulting from a range of HOV alternatives.

REPORT OVERVIEW

The remainder of this report describes the various work tasks that were undertaken in developing the HOV prediction procedures, as well as the results of various tests performed with the final demand and supply models. The report, therefore, is organized along the lines of each study task. Chapter 2 describes the results of a literature review that identified, described, and assessed existing models that could be used to forecast the demand and supply responses due to various HOV strategies. Chapter 3 presents the data requirements that were needed to estimate the new modeling procedure, and assesses the availability of data based on an examination of all major freeway and arterial HOV facilities that either are or have been in operation during the last decade. Key before-and-after data are presented for those freeway sites where such data were found to be available. Chapter 4 describes the model estimation procedures that were used. Finally, the results of tests made with and without the use of the after data are presented. These results are compared to similar forecasts made with the Pivot Point or Incremental Logit Model.

*P. Benjamin et al., Service and Methods Demonstration: Annual Report. (Cambridge, Mass.: TSC, November 1975).

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REVIEW OF EXISTING TRAVEL FORECASTING MODELS

LITERATURE SEARCH

OBJECTIVES AND PROCEDURES EMPLOYED

The objective in conducting this literature search was to identify existing modal split and other forecasting models that either meet, or could be revised to meet, the basic model requirements of the study (i.e., quick response, minimal data, and computational resources). Thus, for example, a model such as UTPS, which requires significant computer, data, time, and monetary resources, was not included in this model review, even though such a model could be used to analyze travel impacts resulting from certain HOV strategies. Therefore, the review focused on manual modeling methods, but included certain computer-based models if it appeared that the model(s) could be simplified for use on a hand-held calculator. Also, a review of these types of models may provide information on a particular subcomponent that could be modified and incorporated into a new travel forecasting procedure.

The literature review began with a search of the National Technical Information Service (NTIS) and Transportation Research Information System (TRIS) computerized data bases. The following key words were used: carpool, bus, preferential, priority, reserve, restrict, exclusive, contraflow, counterflow, ramp metering, bypass lanes, high occupancy vehicles, mode choice, modal choice, mode split, and modal split -- along with various combinations and permutations of these words. A bibliographic search of the subject categories at the Institute of Transportation Studies (ITS) Library

at the University of California was also conducted. In addition, literature searches were made of the CRA Library and the personal libraries of CRA staff members. Other bibliographies reviewed include recent volumes of the Highway Research Information Service (HRIS) and relevant issues of NTISearches.

Typically, a review of a report describing a particular model would also yield citations and/or comparisons of other relevant models. In one particular instance, NCHRP Report 186 presented a useful summary description of 21 "Quick Response" models.* As useful as the summaries are, however, the models in this report generally are not oriented toward the objectives of this study.

The models that were identified as potentially meeting the study objectives are described below.

MODELS DISCOVERED

The literature review uncovered six models that could be used to forecast travel responses due to implementing at least one type of HOV strategy of interest to this study. The six models are:

1. CSI/DOE Pivot Point Logit;
2. Economic-Simulation Model for Priority Lanes on Urban Radial Freeways (K. Small);
3. Planning Model for Transportation Corridors (Talvitie);
4. JHK/Shirley Highway Carpool Mode Shift Model;
5. FREQ6PL-A Freeway Priority Lane Simulation Model; and
6. Transit Corridor Analysis, A Manual Sketch Planning Technique.

In the following section each model, along with its relevant citation, is identified, and a short overview and assessment of the model is presented. In a later section of this chapter, a comparative evaluation of the models is presented in a summary matrix table.

*Arthur Sosslau et al., Travel Estimation Procedures for Quick Response to Urban Policy Issues. (Washington, D.C.: NCHRP Report 186, 1978).

DISCUSSION OF MODELS

MODEL #1 -- CSI/DOE PIVOT POINT LOGIT

DEVELOPMENT

This version of the pivot point logit model* was developed by Cambridge Systematics, Inc., for the Federal Energy Administration and is also contained in a more recent report prepared for the Department of Energy, Washington, D.C.

REFERENCE

A very recent description of the demand model and an example application is contained in Appendix A of the report Urban Transportation Energy Conservation, Case City Applications of Analysis Methodologies, Vol. III; (Washington, D.C.: DOE, October 1979). Additional information on the model is contained in a paper by Moshe Ben-Akiva and Terry Atherton, "Choice Model Predictions of Carpool Demand: Methods and Results," presented at the TRB Annual Meeting, January 1977. A modified and slightly condensed version of this paper is contained in Transportation Research Record No. 637, 1977. The original model description is contained in Cambridge Systematics, Inc., Guidelines For Travel Demand Analyses of Program Measures to Promote Carpools, Vanpools and Public Transportation, prepared for the Federal Energy Administration, November 1976.

MODEL OVERVIEW

The pivot point or incremental logit model is an adaptation of the multinomial logit model that achieves its simplicity by predicting changes in existing travel behavior. The data input requirements consist of information on existing modal shares and changes in transportation level-of-service characteristics. Using an "incremental" approach, in which model coefficients are used to pivot about existing mode shares, reduces data requirements and eliminates the need for detailed socioeconomic and level-of-service data for each household or traffic analysis zone.

*In general, the model coefficients from nearly any multinomial mode choice logit model can be reformulated into a pivot point model. This version of the model has been selected as representative of this class of models.

In order to minimize aggregation bias, the manually applied pivot point model is intended to be used with information on a small set of market segments. However, a first-cut aggregated analysis could be attempted with data representative of one group of users in the corridor being analyzed.

The basic form of the pivot point logit model is:

$$P'_i = \frac{P_i \exp(\Delta V_i)}{\sum_{j=1}^n P_j \exp(\Delta V_j)} \quad (1)$$

where:

- P_i, P'_i = base and revised share of mode i , respectively;
- ΔV_i = change in utility for mode $i = a(\Delta IVTT_i) + b(\Delta OVTT_i)/D + c(\Delta OPTC_i)/INC$;
- $\Delta IVTT_i$ = change in in-vehicle travel time for mode i ;
- $\Delta OVTT_i$ = change in out-of-vehicle travel time for mode i ;
- D = length of trip;
- $\Delta OPTC_i$ = change in out-of-pocket travel cost for mode i ;
- INC = average family income;
- a, b, c = coefficients;
- i, j = number of modes 1, 2, ... n ; and
- n = number of mode choices.

In the TRB paper, results are presented for three validation tests of the model with before-and-after data from the following HOV sites: the Shirley Highway in the Washington, D.C. area, the Santa Monica Freeway in Los Angeles, and the I-35 express-bus-on-metered-freeway project in Minneapolis. The applications illustrate that the model can be applied to a different number of alternative mode choices from a simple auto/bus choice, as in the case of the Shirley Highway application, to the Santa Monica example, which considered two-person carpools and three-or-more-person carpools in addition to the single-passenger auto and bus modes.

In applying the model, the user must determine how many distinct market groups will be used (i.e., will all travelers be aggregated into one average group, or will travelers be subdivided by location, income, number of autos, and/or by other segmentations?). For each group it is necessary to specify changes in transportation level-of-service measures (e.g., in-vehicle and out-of-vehicle travel times and out-of-pocket costs). Predicted mode shares are factored by initial person volumes and auto occupancies to determine vehicle volumes. These can be used with supply models to compute new speeds and travel times that can be compared with initial estimates. If necessary, additional iterations of the model can be made in order to reach equilibrium conditions.

MODEL ASSESSMENT

Because the model can accept varying levels of detail as input as well as consider different modal choice sets, the model has the flexibility to forecast mode shifts under a wide range of alternatives. In fact, if it can be assumed that the change in transportation level of service is a known quantity (a factor that is, however, not easily derived), then the model is potentially capable of evaluating most types of HOV strategies. Traditional speed-volume curves are used to compute revised travel times for freeways and arterials when a lane is either added or subtracted from use. A complementary supply model for a preferential ramp metering alternative is not available, and travel impacts other than mode shifts (e.g., route, time-of-day), are not explicitly considered.

As with nearly all multinomial logit models, the original specification for this model was estimated with cross-sectional data collected at one point in time. The coefficients for this particular model were originally estimated using 1968 data from a random sample of households in Washington, D.C. It would seem likely that the characteristics of the then-existing transit mode (i.e., a local bus), as reflected in the calibration coefficients, are not entirely equivalent to the characteristics of an express bus operating on its own right-of-way. Like many of the mode shift models reviewed, the model was estimated for other purposes and not specifically for the evaluation of mode shifts or, more importantly, volume changes due to different HOV treatments.*

MODEL #2 -- ECONOMIC-SIMULATION MODEL FOR PRIORITY LANES ON URBAN RADIAL FREEWAYS

DEVELOPMENT

This simulation model was developed by Kenneth Small as part of his Ph.D. work at the University of California at Berkeley.

*A description of the logit model and its coefficients is given in Cambridge Systematics, Inc., Carpool Incentives: Analysis of Transportation and Energy Impacts, prepared for the Federal Energy Administration, June 1976.

REFERENCE

A summary of the model is given in Kenneth Small, "Priority Lanes on Urban Radial Freeways: An Economic-Simulation Model," Transportation Research Record No. 637, 1977, pp. 8-13. A more complete description is given in K. Small, "Bus Priority, Differential Pricing, and Investment in Urban Highways," Ph.D. Dissertation, University of California, Berkeley, 1976.

MODEL OVERVIEW

This model operates by combining a simple traffic flow model with a disaggregate modal choice model and, through an iterative equilibration procedure, estimates modal shares for four modes: noncarpool auto (one or two occupants), carpool (three or more occupants), bus with walk access, and bus with auto access (i.e., park-and-ride). The demand model is based on a conventional multinomial logit formulation that can be represented as:

$$P_i = \exp(V_i) / \sum_{j=1}^n \exp(V_j) \quad (2)$$

where:

- P_i = probability of choosing mode i ;
- n = number of available modes; and
- $V_i = V_i(S, X_i)$ = the utility to an individual of mode i as a function of transportation level of service variables and an individual's socioeconomic characteristics.

The demand model includes as transportation LOS variables: travel cost, in-vehicle time, walk time, wait time, and number of transfers; and as socioeconomic variables: income, age, length of residence in neighborhood, and number of children.

Travel speeds or times over the roadway link being analyzed are based on a deterministic queuing model of traffic flow. The form of the model is as follows:

$$\begin{aligned} T &= 60L/S + (D/C-1)W/2 && \text{for } D/C > 1 \\ T &= 60L/S && \text{for } D/C \leq 1 \end{aligned} \quad (3)$$

where:

- T = average travel time in minutes;
- L = length of freeway section in miles;
- S = true speed in miles per hour;
- D = peak demand volume in auto-equivalents/hour;
- C = capacity of bottleneck in auto-equivalents/hour; and
- W = length of peak period in minutes.

Based on the determination of average travel time over the roadway segment, another supply model computes automobile line-haul costs and bus line-haul travel times and costs. The demand and supply models are used with a computerized iterative algorithm to determine equilibrium modal split values and line-haul times and costs for a given total passenger volume.

MODEL ASSESSMENT

The multinomial logit form of the demand model has gained an increasing amount of acceptance in the recent past. In general, the logit formulation to modeling mode shift can reduce the data, time, and computational requirements compared to more traditional aggregate methods. Once the model has been calibrated and the data collected, results can be obtained with minimal computer resources or, in simpler applications, through the use of programmable hand-held calculators or manual worksheets. Due to the particular equilibration procedures employed in this model, however, it is not likely that the approach could be simplified for hand-held calculator use.

In view of the model criteria for this study, the socioeconomic data requirements for this model, although modest in comparison to many models, may not be readily available. (These data could, however, be obtained by conducting relatively small-scale surveys.) Fundamental questions also remain concerning the issue of transferability for these models from one geographic area to another. Compounding the issue is the fact that the model "simulates" base period mode shares and therefore does not explicitly control for base year modal shares on the existing facility. The model does, however, start with a known and fixed total number of trips, and, in theory, the modal constants in the logit utility equation could be "adjusted" to replicate existing conditions.

MODEL #3 -- PLANNING MODEL FOR TRANSPORTATION CORRIDORS

DEVELOPMENT

This model was developed by Antti Talvitie, currently of the Department of Civil Engineering, State University of New York at Buffalo, and stems from work conducted at the University of California, Berkeley.

REFERENCE

An overview of the model is presented in Antti Talvitie, "Planning Model for Transportation Corridors," Transportation Research Record No. 673, 1978. The equilibrium method employed by the model is discussed in I. Hasan and A. Talvitie, "An Equilibrium Mode-Split Model of Work Trips Along a

Transportation Corridor," in E. Visser, ed., Transport Decisions in an Age of Uncertainty -- Proceedings of the Third World Conference on Transport Research. (The Hague: Martinus Nijhoff, 1977).

MODEL OVERVIEW

This model determines corridor level demand by a conventional three-step process of: 1) predicting demand; 2) predicting transportation system level of service; and 3) equilibrating between demand and transportation level of service.

Predicting peak-period travel demand (i.e., mode shares) requires information on a representative sample of households in the study area, including O-D worktrip demands and socioeconomic attributes of individuals in the sample of households chosen. These data are used in a standard multinomial logit model to predict mode shares for the drive alone, shared ride, local express bus, and BART modes. (See the review of Small's model for the logit model form.)

Two service models are used to represent LOS. One set of linear regression equations determines access level of service, and an extension of the point bottleneck method is used to estimate line-haul travel times. The simultaneous solution to the demand and line-haul service equations determines the equilibrium mode shares and, thus, travel volumes. The model is also capable of evaluating the consequences that alternative transportation policies will have on different population groups in the travel corridor being analyzed.

The model was initially developed for a study of the I-580 Corridor in the San Francisco Bay area. The model was used to analyze the effects that widening a section of I-580 and providing exclusive bus and carpool lanes would have on corridor travel. This example application of the model also examined the feasibility of extending the exclusive bus lanes throughout the length of I-580 in the Bay area.

MODEL ASSESSMENT

The major appeal of this model is its ability to consider the interaction between demand and supply changes on both freeways and parallel arterials along a travel corridor. However, as the author acknowledges, the version of the single bottleneck supply model is too insensitive to changes in highway capacity. In particular, changes in volume when $V/C \leq 1$ do not result in any travel time changes.

Although a complete range of line-haul and access modes is considered, the models are tailored toward the specific environment studied (i.e., BART), and are not generalized for application elsewhere. Data requirements are relatively modest. However, specific data on household-level characteristics are required, and these may not always be available without conducting a special survey.

The model currently operates on a computer. If recalibration of the model were not required in order to use it in another locality, it might be possible to simplify the methodology for operation on a programmable calculator.

MODEL #4 -- JHK/SHIRLEY HIGHWAY CARPOOL MODE SHIFT MODEL

DEVELOPMENT

This model was developed by JHK & Associates of Alexandria, Virginia for the Department of Transportation, Urban Mass Transportation Administration.

REFERENCE

A description of this modeling approach can be found in JHK & Associates, "Forecasting Carpool Activity." An extension of the model is also discussed in JHK & Associates, "Carpool Forecasts in the Metro K Line Corridor," prepared for the Metropolitan Washington Council of Governments, March 15, 1978.

MODEL OVERVIEW

Using empirical results derived from one phase of the Shirley Highway demonstration project, this model predicts changes in carpool mode share as a function of changes in the level of service for carpools. It is based on the assumptions that current carpools will choose the fastest path of travel and that modal shifts will occur as the relative travel times between carpools and other modes change for any origin-destination combination. Modes considered include bus, single-occupant vehicle, two-occupant vehicle, three-occupant vehicle, carpool (four or more occupants), and in the study, "Carpool Forecasts in the Metro K Line Corridor," a rapid rail transit mode.

The first step of this five-step procedure involves defining an (origin-destination) zone system for the travel corridor being analyzed, and the final destination area (typically a "core" CBD area). Next, a coarse modal network must be defined that includes the (minimum path) highway network used for each O-D pair, average speeds on each link, and link travel times. From these data, interzonal (O-D) travel times are developed for the base and forecasted alternatives. In the next step, modal trip tables are developed. This requires performing an O-D survey or using the results of a previous survey and applying factoring procedures to update the information. Finally, using data on previous diversions to carpools documented in the report, J. T. McQueen et al., The Evaluation of the Shirley Highway Express-Bus-on-Freeway Demonstration Project; (U.S. Department of Transportation, Urban Mass Transportation Administration, August 1975), diversion factors are developed to indicate the percentage change in existing carpool mode shares.

MODEL ASSESSMENT

The model resembles a manual version of the computer-based UTPS model, except that it lacks an explicit capability for level-of-service feedback. In fact, if output from an existing UTPS model (such as O-D trip tables and travel times) is available, this information can be used as input into this model. However, if this baseline data must be compiled manually, a fair amount of work is required to derive the O-D speeds and travel times. Moreover, the number of calculations increases by approximately the square of the number of zones being considered. Of course, the additional calculations are likely to improve the results of the forecasts.

An important constraint of this model is the lack of a bus priority mode. The model focuses on carpool mode shifts and does not consider shifts to an express bus mode resulting from implementation of an HOV lane for buses. The same general approach used for carpools could, however, be developed for bus-only HOV strategies, although, as noted above, equilibration and data requirements would continue to remain a concern.

MODEL #5 -- FREQ6PL: A FREEWAY PRIORITY LANE SIMULATION MODEL

DEVELOPMENT

This model was developed by Matthys P. Cilliers, Reed Cooper, and Adolf D. May of the Institute of Transportation Studies at the University of California, Berkeley, under the sponsorship of the California Department of Transportation.

The supply model is based on an earlier computer simulation model (i.e., FREQ5CP), also developed at the University of California.

REFERENCE

The model is described in M. Cilliers, et al., FREQ6PL -- A Freeway Priority Lane Simulation Model. (Berkeley, Calif.: Institute of Transportation Studies, University of California, September 1978).

MODEL OVERVIEW

FREQ6PL is a computerized freeway simulation model capable of providing a micro-level assessment of demand shifts and travel flow characteristics resulting from the implementation of normal or concurrent flow-exclusive HOV lanes.* The mode shift component of the model uses travel time differences between priority and nonpriority vehicles to predict shifts from auto to either carpool or express bus modes. Given the change in differences between priority and nonpriority vehicles (FREQ6PL contains a detailed supply-side algorithm to compute the time changes), mode shifts are determined by using demand relationships derived from a multinomial logit model previously estimated with data from San Francisco.** These relationships (or elasticities) were developed for three different priority treatments: bus-only priority lanes, carpool-only priority lanes, and bus/carpool priority lanes. The demand relationships take into consideration three different levels of bus service: high, average (the San Francisco "base" case), and low; as well as two definitions of carpools: two-or-more occupant vehicles and three-or-more occupant vehicles.

*A companion model that can evaluate bus/carpool ramp metering strategies is given in P. P. Jovanis, W. K. Yip, and A. D. May, FREQ6PE -- A Freeway Priority Entry Control Simulation Model; (Berkeley, Calif.: Institute of Transportation Studies, University of California, November 1978). A model (TRANSYT6C) with similar characteristics that can evaluate HOV alternatives on arterial streets is reported in P. P. Jovanis, A. D. May, and A. Deikman, Further Analysis and Evaluation of Selected Impacts of Traffic Management Strategies on Surface Streets; (Berkeley, Calif.: Institute of Transportation Studies, University of California, October 1977).

**The mode shift relationships are reported in A. J. Kruger and A. D. May, Further Analysis and Evaluation of Selected Impacts of Traffic Management Strategies on Freeways; (Washington, D.C.: U.S. Department of Transportation, September 1977).

The model is capable of simulating three distinct time periods: 1) the condition before an alternative is implemented; 2) the short-term after condition (one day after); and 3) the long-term after condition (3-6 months after). In the latter instance, the model examines shifts in modes as well as spatial shifts (i.e., choice of a different route). Travel changes are estimated using detailed speed-flow (demand-capacity) relationships, queuing theory, and shock wave theory.

MODEL ASSESSMENT

The demand relationships used in the model estimate mode shifts in a manner similar to a pivot point logit technique, except that demand is sensitive only to in-vehicle travel time changes. Thus, with equivalent model coefficient values assumed, the demand function is basically a reduced version of the CSI/DOE model described earlier. As such, some of the identical concerns exist involving model transferability and the use of a local bus in the calibration choice set to forecast express bus HOV service.

Clearly, the unique feature of this model is its capability to simulate, at a microscopic level, traffic flow conditions under alternative operating scenarios. However, because of the related data requirements and complex set of calculations required to determine travel times over the roadway section(s) being analyzed, it would not be feasible to implement this model on a hand-held calculator.

MODEL #6 -- TRANSIT CORRIDOR ANALYSIS, A MANUAL SKETCH PLANNING TECHNIQUE

DEVELOPMENT

Initially developed by DeLeuw, Cather & Company, this analysis procedure was based on work undertaken by Planning Research Corporation and two subcontractors, R. H. Pratt Associates and Alan M. Voorhees and Associates, for the Department of Transportation, Urban Mass Transportation Administration, Office of Planning Methods and Support. The procedures were further modified by COMSIS Corporation based on the research performed under NCHRP Project 8-12A, entitled, "Quick Response Urban Travel Estimation Manual Techniques and Transferable Parameters" (see NCHRP Report No. 187).

REFERENCE

The methodology is described in M. Carter et al., Transit Corridor Analysis -- A Manual Sketch Planning Technique. (Washington, D.C.: UMTA, April 1979).

MODEL OVERVIEW

The report referred to above presents a series of manual urban transportation planning tools that can be used for quick, first-cut evaluations of various urban transportation strategies. No computers are required. Rather, computations rely heavily on graphic aids and worksheets.

The technique used to estimate demand is a gravity-type distribution/mode choice model that employs aggregated values of travel time components (in-vehicle time, wait time, transfer time) and travel costs (out-of-pocket, parking, tolls).

The analysis procedure involves identifying the travel corridor to be studied and defining analysis districts so that travel and socioeconomic data can be specified. Transit line-haul volumes (and maximum load point volumes) are calculated manually, with worksheets and/or nomographs, using a standard sequential procedure (i.e., trip generation, trip distribution and mode choice, and assignment). Only work-oriented transit travel is considered; therefore, the approach is geared toward analyzing only transit-based alternatives. Carpool is not considered as an explicit mode, but could be included indirectly by factoring average auto occupancies.

MODEL ASSESSMENT

In comparison with computer-based models, the manual forecasting procedure presented in the handbook can be used as a quick and modestly inexpensive, first-cut screening tool. Data requirements are similarly modest, although under some conditions a considerable amount of data could be required, thereby defeating the objectives of the approach.

The procedure represents a general sketch planning model, and is therefore not particularly formulated toward a straightforward evaluation of a full range of HOV alternatives. In fact, carpools are not considered as an explicit mode in the approach, thereby severely limiting its applicability to this study.

SUMMARY EVALUATION OF MODELS REVIEWED

The preceding section identified and described six models surveyed in a systematic review of the transportation literature. No two of the models were similar in their capabilities to evaluate alternative HOV strategies or in their data input and computational requirements (among other factors). To assist the reader in readily comparing these models, Table 1 lists the model names and identifies which of the six freeway and arterial HOV alternatives the models can directly evaluate. Table 2 presents in a summary matrix format a description of nine pertinent characteristics of each model.

The nine characteristics of the models, which are Column Headings in Table 2, follow:

1. Model Type: A generic description of the demand, supply, and equilibration components of the model.
2. Data Requirements: A list of input data required by the demand and supply components of the model.
3. Computation Requirements: An indication of whether manual or computer capabilities are required and an assessment of staff and implementation time requirements.
4. Past Applications: Indication of whether the approach was used in an actual planning environment.
5. Accuracy: Identification of sources of uncertainty in model coefficients or possible underlying biases in the calibration data set.
6. HOV Application Assumptions: Assumptions inherent in the development or application of the model that relate to analysis of HOVs.
7. Factor Sensitivity: Variables in the model that affect predicted mode shares or travel volumes.
8. Merits: Itemization of favorable aspects of the model.
9. Limitations: Itemization of unfavorable aspects of the model.

Table 1

LIST OF MODEL NAMES AND IDENTIFICATION OF APPLICABLE HOV ALTERNATIVES

Model Number	Name	Applicable HOV Treatments*
1	CSI/DOE Pivot Point Logit Model	1, 2, 3, 4, 5, 6
2	Economic-Simulation Model for Priority Lanes on Urban Radial Freeways	1
3	Planning Model for Transportation Corridors	1, 2, 4
4	JHK/Shirley Highway Carpool Mode Shift Model	1, 3, 6 2 (contraflow only)
5	FREQ6PL - A Freeway Priority Lane Simulation Model**	1, 2 (withflow only)
6	Transit Corridor Analysis, A Manual Sketch Planning Technique	1 (bus only), 2 (bus only), 4 (bus only), 5

*Notes: 1 = Freeways: Separate Carpool-Bus Roadways
 2 = Freeways: Restricted Carpool-Bus Lanes Withflow and Contraflow
 3 = Freeways: Carpool-Bus Ramp Meter Bypass
 4 = Arterials: Withflow Carpool-Bus Restricted Lane
 5 = Arterials: Contraflow Restricted Bus Lane
 6 = Arterials: Reversible Carpool-Bus Lane

**FREQ6PE models HOV Treatment #3; TRANSYT6C models HOV Treatments #4, 5, and 6.

Table 2

SUMMARY CHARACTERISTICS OF MODELS REVIEWED

Model Number	Model Type	Data Requirements	Computation Requirements	Past Applications	Accuracy
1	- o Demand: Incremental form of disaggregate logit - o Supply: Speed a function of V/C - o Equilibration: Iterative solution	o Base mode shares, changes in transportation LOS, socioeconomic data (HH income)	- o Manual worksheet or hand-held calculator (computer required for recalibration) - o Staff: Transportation analyst - o Time requirements: 0.5 to 2 days	- o Model tested with data from Washington, San Francisco, and Minneapolis - o See Chapter 4 for further tests	- o LOS coefficients significant at 5 percent level - o Model underpredicts shift to modes granted priority - o Model estimated with cross-section data (possible source of bias)
2	- o Demand: Multinomial Logit - o Supply: LOS a function of V/C - o Equilibration: Simultaneous Solution	- o Demand: Auto operating and parking costs, auto line-haul time, bus fare, bus walk and bus on-vehicle time, family income, auto ownership, number of children, length of residence, standard work hours - o Supply: Overall average speed, length of road, bottleneck capacity, volume as function of time,	- o Computer required - o Staff: Individuals experienced in logit analysis - o Time: 5-10 person days	o No application in actual environment	- o LOS coefficients significant at 5 percent level - o Demand model estimated with cross-sectional data - o Auto users without access to bus were not included in calibration data set (may underrepresent commuters switching to carpool)

Table continued on following page.

Table 2 (Continued)

SUMMARY CHARACTERISTICS OF MODELS REVIEWED

Model Number	Model Type	Data Requirements	Computation Requirements	Past Applications	Accuracy
3	- o Demand: Multinomial Logit - o Supply: Extension of point bottleneck method - o Equilibration: Simultaneous Solution	- o Demand: In-vehicle walk and transfer time, costs, household income, wage rate and number of autos and drivers per household - o Supply: Free flow travel speeds, bottleneck capacities for freeway and parallel arterials, duration of peak period	- o Computer based procedure - o Recalibration required to transfer model (BART mode included) - o Staff: Experience in logit models - Time Requirements: 5-10 person-days	o Predict impact of HOV lane in I-580 corridor in San Francisco	- o LOS coefficients significant at 5 percent level (except bus headway) - o Demand model estimated on cross-sectional data - o Model not tested with before-and-after data
4	- o Demand: Manual mode shift/diversion - o Supply: None - o Equilibration: None	- o Specification of transportation analysis zones - o Routes and number of (work) trips by mode for all O-D pairs - o Travel times and speeds	- o Manual computation of O-D travel times - o Manual calculation of diversion factors - o Staff: Planning/analytical personnel - Time: 3-8 person-days (depends on number of zones)	- o Methodology applied to Shirley Highway to predict carpool diversions - o Methodology revised to predict mode shares in the Metro K corridor	- o Acceptable accuracy when used to make incremental forecasts - o Accuracy of model unknown for predicting mode shifts for new bus HOV facilities

Table continued on following page.

Table 2 (Continued)

SUMMARY CHARACTERISTICS OF MODELS REVIEWED

Model Number	Model Type	Data Requirements	Computation Requirements	Past Applications	Accuracy
5	- o Demand: Homograph derived from a multinomial logit model - o Supply: Travel time a function of freeway design and traffic flow relationships - o Equilibrium: Iterative algorithm	- o Demand: In-vehicle freeway time differential between carpool/bus/auto - o Supply: Mode split and volumes for vehicles entering at each on-ramp; number of lanes, capacity and length for each priority and nonpriority segment; LGS on parallel streets	- o Computer required - o Staff: Experienced transportation planners or analysts - o Time: 5-10 person-days	o Case study performed on Santa Monica Freeway	o Demand model estimated on cross-sectional data.
6	- o Demand: Gravity type distribution/mode choice - o Supply: None - o Equilibration: None	- o Identification of corridor districts - o Population and employment levels for each district - o Airline distance, parking cost, running cost per mile and average highway speed for each O-D interchange. - o Transit line-haul distance, fare, and mode of access to a line-haul facility for each interchange	- o Manual or graphical calculations - o Staff: Transportation analyst - o Time: Several person-days per strategy	o Application to an HOV treatment not described. Approach has undergone general testing	o Not readily discernible; however, building up of total volumes likely to result in larger errors than incremental approaches.

Table continued on following page.

Table 2 (Continued)

SUMMARY CHARACTERISTICS OF MODELS REVIEWED

<u>Model Number</u>	<u>HOV Application Assumptions</u>	<u>Factor Sensitivity</u>	<u>Merits</u>	<u>Limitations</u>
1	- o Only work trips considered - o Total peak hour volumes remain constant - o Mode shares in sample equals mode split in corridor	o Model sensitive to in-vehicle and out-of-vehicle times, out-of-pocket costs; income and trip length	- o Very low computational requirements - o Model applicable for all HOV strategies - o Minimal data requirements	- o Only work-trip mode shift considered - o Model calibrated with 1968 data on local bus characteristics (versus express bus) - o Effects other than mode split not considered
2	- o Assumes a fixed number of trips - o Only commuter work trips are considered - o Characteristics of access and distribution network are assumed constant - o Travel time for carpoolers would be the same for non-carpoolers	o Model sensitive to all transportation LOS variables	o Workable approach to supply/demand equilibrium	- o Only one type of HOV treatment modeled - o Requires use of household level data - o Documentation not widely available - o Experienced analysts required - o Transferability issues can be serious - o Computer capability required

Table continued on following page.

Table 2 (Continued)
SUMMARY CHARACTERISTICS OF MODELS REVIEWED

Model Number	HOV Application Assumptions	Factor Sensitivity	Merits	Limitations
3	- o Only work trips considered - o Travel speed remains constant unless $V > C$ - o Carpool mode consists of all automobiles with two or more occupants	o Mode shifts are sensitive to all transportation LOS. However, unless $V > C$, model is not sensitive to volume or capacity changes	- o Model has equilibration procedure - o Model can simulate volume changes on parallel arterials - o Data requirements are relatively modest - o Access and line-haul mode choice decisions are considered	- o Computer facilities required - o Household-level data required - o Calibrated model includes BART mode - o Mode shares of representative households may not equal mode shares in corridor
4	- o No feedback to LOS - o Mode shifts sensitive to travel time changes only - o Fixed trip table assumed (trip assignment changes for carpools only)	o Mode shift affected by travel time only	- o Conceptually simple and straightforward methodology - o No computer required	- o Data if not readily available could be time consuming and costly to assemble - o Calculations, while simple, are time consuming - o Methodology does not presently consider bus a priority mode

Table continued on following page.

Table 2 (Continued)

SUMMARY CHARACTERISTICS OF MODELS REVIEWED

<u>Model Number</u>	<u>HOV Application Assumptions</u>	<u>Factor Sensitivity</u>	<u>Merits</u>	<u>Limitations</u>
5	- o Constant number of person trips assumed - o Spatial shifts made before mode shifts - o Parallel arterial speed held constant	o Mode shifts are sensitive to time differential changes	- o Simple approach to demand estimation - o Demand data requirements are minimal - o Detailed estimation of traffic flow impacts	- o Extensive computer requirements - o Limited validation testing with before/after data - o Transferability properties of demand model not known - o Demand sensitive only to in-vehicle time changes
6	- o Auto is treated as a generic mode (no separate carpool mode) - o All corridor travel terminates in CBD. - o Only work-oriented transit travel considered - o No LOS feedback	o Model sensitive to a full range of transportation impedances	- o Can be quick, inexpensive, coarse screening tool - o Requires relatively modest amounts of data - o Good documentation	- o Does not consider carpool as a specific mode - o Approach not user oriented toward HOV facilities - o Calculations can be time consuming - o Procedure not validated against existing HOV applications

Of the six models reviewed and listed in Table 2, only the JHK/Shirley Highway Carpool Mode Shift Model was developed based on a combination of travel behavior theory and empirical evidence obtained from an actual implementation of an HOV strategy (for carpools only, however). None of the other five model formulations was based (or modified) on actual empirical findings. Moreover, only the CSI/DOE Pivot Point Logit Model has undergone a multiple validation phase in which model forecasts are "tested" against actual before-and-after data from various HOV sites. Consequently, because of its user-oriented documentation and its potential applicability in evaluating various HOV strategies, the CSI/DOE Pivot Point Logit Model (Model #1) was included for model testing. The results of these tests are discussed in Chapter 4.

3

DATA REQUIREMENTS AND DATA AVAILABILITY FOR MODEL DEVELOPMENT AND TESTING

This chapter is divided into three sections. The first section consists of a description of the data required in the development and testing of a model for forecasting travel volumes due to HOV strategies. The second section describes the procedures that were employed to collect the data, while the third section presents an assessment and tabulation of the key before-and-after data items for those freeway HOV sites that meet the minimum data requirements. The model that was initially proposed and later estimated with the data is described in more detail in Chapter 4.

MODEL DATA REQUIREMENTS

In Chapter 2, existing models that either meet, or could easily be revised to meet, the objectives of this study were reviewed and critiqued. The main conclusion of that review was that none of the currently available travel demand models has been estimated using a broad cross-section of empirical before-and-after data available from HOV demonstrations implemented over the preceding 10 years. Consequently, it was proposed that a model be developed and tested using before-and-after data from previously implemented HOV facilities. For purposes of validation and comparison, information was also collected to test the pivot point logit procedure. The model specification and data requirements for each of these models are described next.

PROPOSED HOV MODEL

The initial list of data items (variables) in the model specification included the traditionally important measures that are affected most by the implementation of an HOV facility (e.g., autos by occupancy level, bus passengers, in-vehicle travel times for the priority and nonpriority modes), as well as those factors that could, in some selected instances, have been affected due to the implementation of a particular HOV treatment (e.g., auto operating costs, tolls, etc.). It was clear at the outset that the specification of the proposed model for this project would be limited only by the common set of data that could be tabulated for each of the HOV facilities included in the final estimation data set (subject of course to standard hypotheses concerning variables that influence travel choice behavior and to the constraints bearing on the objectives of the model to be developed). Thus, as a first step, a comprehensive list of travel supply and/or impedance variables that typically have been shown to have an impact on travel behavior were compiled onto a worksheet. The objective of such a list was not to limit prematurely the types of data that should be tabulated at the outset, if in fact the data existed. Later it became possible, after examining evaluation reports of "data rich" HOV sites, to settle upon a list of "key" data items.

The common set of (key) data required for at least two study periods for each site were: volume of vehicles (or persons) traveling on the general purpose and priority lanes; travel speeds and times of vehicles on the general purpose and priority lanes; HOV length; and roadway geometric descriptions (i.e., number of lanes and/or capacity). The first or "before" time period represents conditions prior to the implementation of the HOV treatment in question, while the second period reflects conditions approximately one year after the implementation of the HOV strategy. If an HOV treatment were implemented in phases (e.g., bus-only with the later inclusion of carpools), additional ("before-after") periods could be included. If available, data were tabulated for conditions representing different (hourly) time slices throughout the peak commuting periods, or, at the minimum, for conditions at the peak hour in the peak direction. (To the extent possible, the a.m. peak hour period and direction were used for consistency purposes across HOV sites.)

PIVOT POINT LOGIT MODEL

A separate worksheet was developed for the data requirements of the Pivot Point Logit Model. Following a strategy similar to that described above, space was provided on the worksheet to record a broader range of information than typically would be available for every site. The one key data item required for all sites, however, was the change in in-vehicle travel time for different market segments. At a minimum, this data item is required for priority and nonpriority vehicles. Base mode shares were determined from the trip quantity volumes recorded on the worksheets for the proposed model.

PROCEDURE USED IN DATA COLLECTION

IDENTIFICATION OF HOV SITES

A list of all operating or previously operating freeway and arterial HOV sites for which data were potentially available for use in this study was compiled during the literature review phase and is presented in Table 3. The sites are classified by the six pertinent HOV priority strategies, as well as by a breakdown of the freeway restricted carpool/bus lane HOV strategy into withflow and contraflow sites.

Some of the relevant overview or compendium reports that proved useful in accomplishing this task are listed below:

- U.S. Department of Transportation, Priority Techniques for High Occupancy Vehicles: State-of-the-Art Overview, November 1975.
- Ronald Fisher and Howard Simkowitz, Priority Treatment for High Occupancy Vehicles in the United States: A Review of Recent and Forthcoming Projects, TSC and UMTA, August 1978.
- N. D. Lea Transportation Research Corporation, Lea Transit Compendium: Bus Transit, Vol. II, No. 7, 1975.
- Public Technology, Inc., Manual on Planning and Implementing Priority Techniques for High Occupancy Vehicles: Technical Guide, U.S. DOT, July 1977.
- M. J. Rothenberg, Priority Treatment for High Occupancy Vehicles: Project Status Report, Federal Highway Administration, March 1977.

The sites presented in Table 3 were also checked against a master list of HOV priority facilities maintained by FHWA.

COMPILATION OF AVAILABLE DATA

Three approaches to data collection were identified. In order of preference, they are: 1) reliance on the use of (demonstration) evaluation reports; 2) telephone contacts and correspondence; and 3) personal site visits. A list of HOV evaluation reports and other citations was compiled using information gathered during earlier study tasks and through the use of NTIS and TRIS computer searches. Both an on-line and off-line (batch) search of the TRISNET system was performed using the facilities of the ITS Library at the University of California. This bibliography was further extended by examining the reference lists of the compendium reports cited above.

Table 3

SUMMARY OF HOV FACILITIES

<u>Type of HOV Treatment</u>	<u>City</u>	<u>Facility Name</u>
Freeway: Separate Carpool/Bus Lanes	Washington, D.C.	Shirley Highway
	Los Angeles	San Bernardino
	Pittsburgh	South PATway
	San Francisco	I-580
Freeway: Restricted Carpool/Bus Lanes -- Withflow	Boston	I-93
	Honolulu	Moanalua
	San Francisco	U.S. 101
	San Diego	Route 163
	Portland	Banfield Freeway
	San Francisco	I-280
	San Francisco	Oakland Bay Bridge
	Los Angeles	Santa Monica
	Boston	S.E. Expressway (1977)
	Miami	I-95
Freeway: Restricted Carpool/Bus Lanes -- Contraflow	Boston	S.E. Expressway (1971)
	New York	Lincoln Tunnel, I-495

Table continued on following page.

Table 3 (Continued)

SUMMARY OF HOV FACILITIES

<u>Type of HOV Treatment</u>	<u>City</u>	<u>Facility Name</u>
Freeway: Carpool/Bus Ramp Meter Bypass	New York	Long Island Expressway
	Houston	I-45
	Minneapolis	I-35W
	Milwaukee	East-West Freeway
	Dallas	North Central Freeway
	Dallas	I-30
	San Francisco	I-280
	San Diego	I-94
	Los Angeles	I-5, I-10, I-405, I-605 U.S. 101
Arterial: Withflow Carpool/Bus Restricted Lane	Miami	South Dixie, U.S. 1
	Miami	NW 7th Ave.
	Seattle	SR 522
	Chicago	Washington St.
	New Orleans	Canal St.

Table continued on following page.

Table 3 (Continued)

SUMMARY OF HOV FACILITIES

<u>Type of HOV Treatment</u>	<u>City</u>	<u>Facility Name</u>
	Denver	15th and 17th St.
	Denver	Broadway and Lincoln
	San Francisco	Geary-O'Farrel Sutter-Post St.
Arterial: Contraflow Restricted Bus Lane	Indianapolis	College Ave.
	Honolulu	Kalaniana'ole
	Minneapolis	Marquette/Second Ave.
	Louisville	Second and Third Sts.
	Los Angeles	Spring St.
Arterial: Reversible Carpool/Bus Lane	Miami	NW 7th Ave.
	Portland	Barbur Blvd.

SOURCE: Compiled by Charles River Associates.

Individuals at local agencies were contacted when an evaluation report was not available or to clarify information contained (or not contained) in a cited document. If possible, internally-produced reports were also obtained. The following section of this chapter discusses the results of the data collection process.

ASSESSMENT AND DESCRIPTION OF DATA AVAILABLE BY HOV SITE

Table 4 summarizes the data available at each of the HOV sites listed in Table 3. For each HOV facility the following five items of information are listed:

- City: Location of HOV facility;
- Facility: Commonly referenced name of facility;
- Contacts Made: Names of individuals contacted (if necessary);
- Reports Examined: Citations of reports reviewed and used. (Reports obtained but not relied upon are not listed.); and
- Adequacy of Data: Brief assessment of the adequacy and completeness of the data available.

As indicated in the table, very few of the arterial HOV facilities have the minimum key data elements for both the before and after time periods. Basically, this is because few formal before and after evaluations were undertaken for arterial-related projects. On the other hand, because of their (relatively) higher implementation costs, along with their greater potential to monitor and measure the resultant travel impacts, freeway-based HOV projects were the subject of more rigorous evaluations. As a result, they were more likely to have key before and after data required for model estimation. In particular, nine of the freeway facilities have one or more sets of the required before and after key data. Since three of the sites (San Bernardino, U.S. 101, and I-95 in Miami) have data on two different project phases, a total of 21 data observations are available.

Two types of data were not available for nearly all sites examined. The first was parallel facility information on level-of-service and travel diversion impacts. Consequently, it is not possible to analyze systematically the separate effects due to route diversion. The second area where little data existed was for travel volumes disaggregated by each individual auto occupancy level (i.e., 1, 2, 3, or 4+ person vehicles) for both the before and after time periods. However, traffic volume data were available for the number of nonpriority automobiles using the nonpriority lanes in the before-and-after time period, as well as for the number of priority-eligible automobiles using the general purpose lanes in the before period and, subsequently, the HOV lane(s) in the after period. What is not

Table 4

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- SEPARATE CARPOOL/BUS ROADWAYS

CITY AND FACILITY: Washington, D.C.: Shirley Highway.

Contacts Made: Evaluation reports available.

Reports Examined: McQueen, James T. Final Report: The Evaluation of the Shirley Highway Express-Bus-on-Freeway Demonstration Project. U.S. Department of Transportation, August 1975.

Miller, N. Craig and Robert B. Deuser. Enforcement Requirements for High-Occupancy Vehicle Facilities. Beiswenger, Hock and Associates, Inc., December 1978.

Allen, J. C. and M. J. Rothenberg. Evaluation of Alternative Traffic Operation Plans for the Commuter on the Shirley Highway in Virginia. JHK & Associates, July 1977.

N. D. Lea Transportation Research Corporation. Lea Transit Compendium -- Bus Transit. Vol. II, No. 7, 1975.

Adequacy of Data: Partial data exist for five separate time periods; however, key before-and-after data are available only for the introduction of 4+ carpools. Average travel times were estimated using Census data and disaggregation of automobiles by occupancy level is not available, except for 4+ person carpools.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- SEPARATE CARPOOL/BUS ROADWAYS

CITY AND FACILITY: Los Angeles, CA: San Bernardino Freeway.

Contacts Made: Sydwell Flynn (Ms.), John Crain & Associates,
Menlo Park, CA, (415) 327-8101.
Larry Foutz, Southern California Association of
Governments, Los Angeles, CA, (213) 385-1000.

Reports Examined: Crain and Associates. Evaluation of Express Busway on
San Bernardino Freeway - Third Year Report, May 1976.

Bigelow-Crain Associates. Second Year Report: San
Bernardino Freeway Express Busway Evaluation, September
1975.

Crain and Associates. First Year Report: San
Bernardino Freeway Express Busway Evaluation, February
1974.

Crain and Associates. San Bernardino Freeway Express
Busway Evaluation of Mixed-Mode Operations, July 1978.

California Department of Transportation. Freeway Lanes
for High-Occupancy Vehicles, (Third Annual Progress
Report), December 1973.

Adequacy of Data: Two sets of before-and-after data exist, one for the
opening of the facility and the second for the change
from bus-only to bus/3+ person operation. Total travel
times are estimated using average trip length and change
in travel times on the facility as given in the
reports.

CITY AND FACILITY: Pittsburgh, PA: South PATway.

Contacts Made: R. M. Parker, Port Authority of Allegheny Co.,
(412) 237-7000.

Reports Examined: None produced.

Adequacy of Data: Before-and-after data are not available.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- SEPARATE CARPOOL/BUS ROADWAYS

CITY AND FACILITY: San Francisco, CA: I-580.

Contacts Made: Leonard Newman, Chief of Highway Operations, CALTRANS,
(415) 557-2342.

Reports Examined: None produced.

Adequacy of Data: Before-and-after data are not available.

HOV PRIORITY TYPE:
FREEWAYS -- RESTRICTED CARPOOL/BUS LANES, WITHFLOW

CITY AND FACILITY: San Francisco, CA: Oakland Bay Bridge HOV Lanes.

Contacts Made: M. Scott MacCalden Jr., CALTRANS,
(415) 557-2088.
Information Office, California Department of
Transportation, (415) 557-1840.

Reports Examined: MacCalden, Jr., M. Scott and Charles A. Davis. Report
on Priority Lane Experiment on the San Francisco-Oakland
Bay Bridge. California DPW, Division of Bay Toll
Crossings, April 1973.

Adequacy of Data: Results not considered transferable to reserved HOV
lanes on freeways, in part because of the change in toll
structure. Otherwise, key before-and-after data are
available.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- RESTRICTED CARPOOL/BUS LANES, WITHFLOW

CITY AND FACILITY: Boston, MA: I-93.

Contacts Made: Jerry Murphy, Massachusetts Department of Public Works,
(617) 727-5050.

Reports Examined: Perkins, L. T. "Success of Special Lane for Carpools on
I-93." Interoffice Correspondence, Department of Public
Works, May 21, 1974.

Adequacy of Data: Volume and travel time data for the 0.5-mile section of
road indicate an improvement in level of service and
number of 3+ vehicles. However, data are not available
for bus ridership, average total trip length, and
average travel time.

CITY AND FACILITY: Honolulu, HI: Moanalua Freeway.

Contacts Made: Evaluation reports available.

Reports Examined: Kaku, D. et al. Evaluation of the Moanalua Freeway
Carpool/Bus Bypass Lane. Final Report. JHK &
Associates and Alan M. Voorhees, Alexandria, VA, August
1977.

U.S. DOT. Technology Sharing: Priority Techniques for
High Occupancy Vehicles. November 1975, p. A-3.

Adequacy of Data: Data for the before period are not applicable, as the
entire freeway was under construction prior to the
opening of the HOV lane.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- RESTRICTED CARPOOL/BUS LANES, WITHFLOW

CITY AND FACILITY: San Francisco, CA: U.S. 101 (Marin County).

Contacts Made: James McCrank, CALTRANS, (415) 557-2162.
Gale Bach, Metropolitan Transportation Commission,
(415) 849-3223.

Reports Examined: CALTRANS. Bus/Carpool Lanes, Route 101, Marin County,
Evaluation Report. March 1977.

Adequacy of Data: Two sets of before-and-after data exist in complete
form. Total travel times were estimated using average
trip length provided by the MTC. Carpools are
disaggregated into 2-person and 3+ person carpools.

CITY AND FACILITY: San Diego, CA: Route 163.

Contacts Made: Evaluation reports available.

Reports Examined: Garcia, J. M. Exclusive Bus and Carpool Lanes Installed
and Operated by the State of California. February
1975.

Adequacy of Data: A complete set of the key data is not available.

CITY AND FACILITY: Portland, OR: Banfield Freeway.

Contacts Made: Earl Mershon, Oregon DOT, (503) 238-8226.

Reports Examined: Oregon Department of Transportation, Metropolitan
Branch. Banfield High Occupancy Vehicle Lanes. Final
Report. March 1978.

Adequacy of Data: Key before-and-after data exist for both phases of this
project. Total average travel times were estimated
using average trip length.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- RESTRICTED CARPOOL/BUS LANES, WITHFLOW

CITY AND FACILITY: San Francisco, CA: I-280.

Contacts Made: Leonard Newman, Chief of Highway Operations, CALTRANS,
(415) 557-2342.

Reports Examined: None produced.

Adequacy of Data: Before-and-after data are not available.

CITY AND FACILITY: Los Angeles, CA: Santa Monica Freeway.

Contacts Made: Evaluation reports available.

Reports Examined: Billheimer, J. W., et al., (SYSTAN, Inc.). The Santa Monica Freeway Diamond Lanes, Volumes I and II. September 1977.

Adequacy of Data: Project terminated after 21 weeks.

CITY AND FACILITY: Miami, FL: I-95.

Contacts Made: Evaluation reports available.

Reports Examined: Wattleworth, Joseph A., et al. Report II-1: Evaluation of the I-95 Express Bus and High Occupancy Vehicle Priority Systems. September 1978.

Wattleworth, Joseph A., et al. Report II-2: Evaluation of the Effects of the Exclusive Bus/Carpool Lane Priority System on Vehicular and Passenger Movements. Transportation Research Center, University of Florida, September 1978.

Adequacy of Data: Two complete sets of before-and-after data exist. Average total travel times are estimated from secondary data provided in the evaluation reports. Disaggregation of automobiles by occupancy level is nearly complete.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- RESTRICTED CARPOOL/BUS LANES, WITHFLOW

CITY AND FACILITY: Boston, MA: Southeast Expressway (1977).

Contacts Made: Daniel Brand, Charles River Associates, (617) 266-0500.

Reports Examined: Brand, Daniel et al. Southeast Expressway Reserved Lane for Buses and Carpools. Presented at the 57th Meeting of the Transportation Research Board, January 1978; also contained in Transportation Research Record 663.

Simkowitz, Howard. Southeast Expressway High Occupancy Lane Evaluation Report. Final Report, TSC, May 1978.

Adequacy of Data: A complete set of before-and-after data exists. Disaggregation of automobiles by occupancy level is not complete. Total travel time estimates are based on the average commuter travel time given in the cited reports.

HOV PRIORITY TYPE:
FREEWAYS -- RESTRICTED CARPOOL/BUS LANES, CONTRAFLOW

CITY AND FACILITY: Boston, MA: Southeast Expressway (1971).

Contacts Made: Ed Fitzgerald, Massachusetts Department of Public Works, (617) 727-6414.

Reports Examined: Cantone, V. J. The Exclusive Bus Lane Demonstration on the Southeast Expressway. Commonwealth of Massachusetts, Department of Public Works, undated.

Adequacy of Data: Complete before-and-after data exist. Average total travel times were estimated based on average peak hour commuter travel times given in the 1977 evaluation reports. Automobile volumes are not disaggregated by occupancy level.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- RESTRICTED CARPOOL/BUS LANES, CONTRAFLOW

CITY AND FACILITY: New York, NY: Lincoln Tunnel, I-495.

Contacts Made: Leon Goodman, NY and NJ Port Authority, (212) 466-8397.
Walter Colvin, NY and NJ Port Authority,
(212) 466-7005.

Reports Examined: Goodman, Leon. Interstate 495 Exclusive Bus Lane.
Tri-State Regional Planning Commission, July 1972.

Miller, N. Craig and Robert B. Deuser. Enforcement
Requirements for High-Occupancy Vehicle Facilities.
Beiswenger, Hoch and Associates, Inc., December 1978.

Charles River Associates. Ridesharing Market Study.
Final Report, prepared for Transportation Systems
Management Planning, Port Authority of New York and New
Jersey, June 1980, pp. 4-11.

Adequacy of Data: Key before-and-after data available. Average travel
times were estimated using average commuter trip
lengths. Automobile volumes are not disaggregated by
occupancy level.

CITY AND FACILITY: Houston, TX: I-45, North Freeway.

Contacts Made: Joseph Goodman, UMTA, (202) 426-4984.

Reports Examined: McCasland, William R. Evaluation of the First Year of
Operation I-45 Contraflow Lane, Houston. Texas
Transportation Institute, October 1980.

Public Technology, Inc. "SMD Briefs: Houston
Contraflow Lane." Various dates.

Adequacy of Data: This site was in operation for less than one year at the
time of this evaluation.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- RESTRICTED CARPOOL/BUS LANES, CONTRAFLOW

CITY AND FACILITY: New York, NY: Long Island Expressway, I-495.

Contacts Made: Sam Swartz, (212) 566-2980.

Reports Examined: New York City Department of Traffic. Long Island Expressway Exclusive Bus Lane Cost-Benefit Analysis. March 1973.

Adequacy of Data: Key before-and-after data are not available.

HOV PRIORITY TYPE:
FREEWAYS -- CARPOOL/BUS RAMP METER BYPASS

CITY AND FACILITY: Los Angeles, CA: US 101, I-605, I-405, I-5, I-10.

Contacts Made: Gary Bork, Senior Engineer, CALTRANS, (213) 620-2408.

Reports Examined: Goodell, Robert G. B. Bypass Lanes for Carpools at Metered Ramps Summary Report. California Department of Transportation, October 1975.

Adequacy of Data: Extensive data on ramp delays, HOV savings, and travel times for each ramp site and freeway have been collected, but they are not in readily retrievable format.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- CARPOOL/BUS RAMP METER BYPASS

CITY AND FACILITY: Minneapolis, MN: I-35W (Bus Only).

Contacts Made: Adell Lari, Minnesota Department of Transportation,
(612) 341-7500.
Richard Wolsfeld, Bather-Ringrose-Wolsfeld,
(612) 379-7878.

Reports Examined: Bather-Ringrose-Wolsfeld, Inc. Final Report for the
I-35W Urban Corridor Demonstration Project.
Metropolitan Council, St. Paul, August 1975.

Adequacy of Data: Data on the before-and-after phases are available.
There is no disaggregation by vehicle occupancy since
the priority is given only to buses. Total travel time
was estimated using information in the report.

CITY AND FACILITY: Milwaukee, WI: East-West Freeway.

Contacts Made: None required.

Reports Examined: None produced.

Adequacy of Data: Secondary sources indicate that key before-and-after
data are not available.

CITY AND FACILITY: Dallas, TX: North Central Freeway.

Contacts Made: Mildred Cox, Dallas Transit System, (214) 670-4028.

Reports Examined: None produced.

Adequacy of Data: Before data are not available.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
FREEWAYS -- CARPOOL/BUS RAMP METER BYPASS

CITY AND FACILITY: Dallas, TX: I-30.

Contacts Made: Kirti Patel, Dallas Transit System, (214) 670-4028.

Reports Examined: Office of Transportation Programs. Bus and Carpool Bypass Ramp Operations in Dallas. City of Dallas, July 1979.

Adequacy of Data: Before data are not available.

CITY AND FACILITY: San Francisco, CA: I-280.

Contacts Made: Leonard Newman, Chief of Highway Operations, CALTRANS, (415) 557-2342.

Reports Examined: None produced.

Adequacy of Data: Key before-and-after data not available.

CITY AND FACILITY: San Diego, CA: I-94.

Contacts Made: Don Day (for Stew Harvey), Traffic Systems Department, CALTRANS, (714) 294-5383.

Reports Examined: None currently available.

Adequacy of Data: Evaluation reports are not currently available.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
ARTERIALS -- WITHFLOW CARPOOL/BUS RESTRICTED LANE

CITY AND FACILITY: Miami, FL: S. Dixie Highway, U.S. 1.

Contacts Made: Roy Strong, Dade County Office of Transportation
Administration, (305) 579-5691.

Reports Examined: Florida Department of Transportation, Metropolitan Dade
County. U.S. 1/South Dixie Highway Transportation
Demonstration Project. November 1975.

Adequacy of Data: Most key before-and-after data are available. Average
travel distances are provided in the report. Carpools
are not disaggregated by occupancy level.

CITY AND FACILITY: Miami, FL: NW 7th Avenue.

Contacts Made: Evaluation reports available.

Reports Examined: Wattleworth, Joseph A., et al. Report I-1, Evaluation
of the NW 7th Avenue Express Bus and Bus Priority
System. Final Report. Transportation Research Center,
University of Florida, September 1975.

Adequacy of Data: Data on before-and-after time periods exist and are
complete. No disaggregation of automobiles by occupancy
level is made, however. (Construction on I-95 was
ongoing during the operation of the NW 7th Avenue
priority treatment.)

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
ARTERIALS -- WITHFLOW CARPOOL/BUS RESTRICTED LANE

CITY AND FACILITY: Seattle, WA: SR 522.

Contacts Made: Clifford Kurtzweg, (206) 464-7592.

Reports Examined: No evaluations have been performed.

Adequacy of Data: Data not available.

CITY AND FACILITY: Chicago, IL: Washington Street.

Contacts Made: Bob Janel, Chicago Transit Authority, (312) 664-7200.

Reports Examined: None available.

Adequacy of Data: Key before-and-after data are not available.

CITY AND FACILITY: New Orleans, LA: Canal Street.

Contacts Made: Bob Dombourian, New Orleans Public Service, Inc.,
(504) 586-2514.

Reports Examined: None produced.

Adequacy of Data: Before-and-after data are not available.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
ARTERIALS -- WITHFLOW CARPOOL/BUS RESTRICTED LANE

CITY AND FACILITY: Denver, CO: 1) 15th & 17th Street Bus Lanes; and
2) Broadway and Lincoln St. Bus Lanes.

Contacts Made: Bill Bryne, Denver Regional Transit District,
(303) 759-1000, Ext. 333.

Reports Examined: Regional Transportation District. Broadway/Lincoln Bus
Lane Operational Analysis. TSM Division, Denver, CO.,
March 1980.

Adequacy of Data: Automobile volumes in the before period were not
collected for both facilities.

CITY AND FACILITY: San Francisco, CA: Geary-O'Farrel; Sutter-Post Street.

Contacts Made: Gilbert Sams, MUNI, (415) 558-3371.

Reports Examined: San Francisco Department of Public Works. Exclusive
Transit Lanes on Sutter and Post Streets. March 31,
1977.

SYSTAN, Inc. San Francisco Transit Priority Street
Treatment Demonstration Baseline Conditions Report.
September 1979.

Adequacy of Data: Travel volume data are not available.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
ARTERIALS -- CONTRAFLOW RESTRICTED BUS LANE

CITY AND FACILITY: Indianapolis, IN: College Avenue.

Contacts Made: Mr. Gobis, METRO, (317) 635-2100, Ext. 10.

Davie, Bob. "College Avenue-Southbound Coach Lane."
Memo to Tom Weakley of METRO, May 28, 1980.

Adequacy of Data: No before data exist.

CITY AND FACILITY: Honolulu, HI: Kalaniana'ole Highway.

Contacts Made: Evaluation reports available.

Reports Examined: Kaku, D., et al. Evaluation of the Kalaniana'ole
Highway Carpool/Bus Lane. JHK & Associates and Alan M.
Voorhees, August 1977.

Adequacy of Data: Key data items exist for the before period and two
years after the opening of the HOV lane. Automobile
volumes are disaggregated by 3+ person and <2 person
vehicles.

CITY AND FACILITY: Minneapolis, MN: Marquette/Second Avenue.

Contacts Made: David Schnieder, Transportation Systems Center,
(617) 494-2377.

Reports Examined: Report purportedly produced but could not be located.

Adequacy of Data: Secondary sources indicate that key data are not
available.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
ARTERIALS -- CONTRAFLOW RESTRICTED BUS LANE

CITY AND FACILITY: Louisville, KY: Second & Third Streets.

Contacts Made: Evaluation reports available.

Reports Examined: Schimpeler-Corradino Associates. Urban Corridor Demonstration Program: Early Implementation Phase, Louisville, Kentucky. Urban Mass Transportation Administration, June 1972.
Alan M. Voorhees. Status of the Urban Corridor Demonstration Program. Report DOT P6500.2, July 1974.

Adequacy of Data: Secondary sources indicate that not all key data are available.

CITY AND FACILITY: Los Angeles, CA: Spring Street.

Contacts Made: Los Angeles Department of Transportation, (213) 485-2265, and Traffic Control Office, (213) 485-2265.

Reports Examined: Public Technology, Inc. "Case Study: Los Angeles, California/Spring Street Contra-Flow Bus Lane," Appendix C in Manual on Planning and Implementing Priority Techniques for High Occupancy Vehicles: Technical Guide. July 1977.

Adequacy of Data: Key before-and-after data are not available.

Table continued on following page.

Table 4 (Continued)

ANALYSIS OF DATA AVAILABILITY FOR EXISTING HOV SITES

HOV PRIORITY TYPE:
ARTERIALS -- REVERSIBLE CARPOOL/BUS LANE

CITY AND FACILITY: Miami, FL: NW 7th Avenue.

Contacts Made: Evaluation reports available.

Reports Examined: Wattleworth, Joseph A., et al. Report I-1, Evaluation of the NW 7th Avenue Express Bus and Bus Priority Systems. Final Report. Transportation Research Center, University of Florida, September 1975.

Adequacy of Data: Data on five data points exist and are complete. No disaggregation of automobiles by occupancy level is made, however. (Construction on I-95 was ongoing during the operation of NW 7th Avenue priority treatments.)

CITY AND FACILITY: Portland, OR: Barbur Boulevard.

Contacts Made: Max J. Klotz, Metro Program Manager, (503) 238-8231.
Byron York, Tri-Met, (503) 238-4897.

Reports Examined: "Summary of Findings -- Barbur Boulevard [sic] Bus Lane Evaluation." A series of graphs and a short summary of a technical evaluation of the impacts of the Barbur Boulevard Bus Lane by Ron Higbel of the Oregon Department of Transportation.

Adequacy of Data: Before traffic volumes and travel times are not available.

available from this information is what modes were previously used by the new carpoolers using the HOV facility.

The key before-and-after modal volumes and level-of-service characteristics that were obtained for the 12 freeway HOV facilities (or phases) are given in Table 5. (Table 6 summarizes the HOV treatments that were in operation during the before-and-after time period, while Table 7 lists the implementation date of the HOV strategy and the dates when the before-and-after data were collected.) For each site, Table 5 presents the following information:

1. Nonpriority Auto Volumes and Capacity: Peak hour (a.m.) volume of automobiles not eligible to use the HOV facilities for the before and after time periods; capacity of general purpose lanes for the before-and after-time periods.
2. Priority Auto Volumes: Peak hour (a.m.) volume of automobiles eligible to use the HOV facility for the before and after time periods.
3. Transit Ridership: The before-and-after volume of bus riders in the a.m. peak hour who use the HOV lanes in the after time period.
4. Average Total Travel Time: Average total travel time (in minutes) for priority and nonpriority vehicles for the before and after time periods.
5. Length of HOV lane(s) in miles.
6. HOV Time Advantage: The travel time saved by using the HOV facility compared to the non-HOV lanes in the after time period (i.e., nonpriority after time minus priority after time).
7. Nonpriority Δ IVTT: Change in in-vehicle travel time from the before to the after time period for nonpriority automobiles.
8. Priority Δ IVTT: Change in in-vehicle travel time from the before to the after time period for the priority-eligible vehicles; (in two instances it includes the change in bus travel time while buses were already on the HOV lane in the before period).
9. Speed: Average speed on the HOV section of roadway for vehicles on the general purpose and HOV lane in the before and after time periods.
10. Average Trip Length: Average trip distance in miles of all users on the HOV roadway.

Seven of the before and after sets of data represent the initial start of an HOV priority facility. Four others (Shirley Highway, San Bernardino

Table 5

SUMMARY OF KEY DATA FOR FREEWAY HOV SITES

HOV Facility	VOLUME: Nonpriority Autos				VOLUME: Priority Autos		Transit Ridership		Average Travel Time (Minutes)				HOV Length (Miles)
	(VPH)				(VPH)		Before	After	General Purpose		HOV		
	Before	Cap	After	Cap	Before	After			Before	After	Before	After	
Shirley Highway	4896	5880	5126	5880	195	758	7900	8756	56.2	58.3	37.5	38.3	9.
San Bernardino-I	7300	7500	7300	7500	NPA	NPA	402	1017	44.4	45.3	NPL	36.9	7.
San Bernardino-II	7067	7500	7277	7500	299	576	2490	2708	45.7	46.1	34.0	35.3/34.0*	7/11*
U.S. 101-I	5314	5558	5330	5616	NPA	NPA	3370	3572	35	35	NPL	32.2	3.8
U.S. 101-II	5125	5616	5333	5616	205	288	3572	3646	35	33.1	32.2	32.2	3.8
Banfield Freeway-I	3713	3900	3845	3900	37	180	340	570	21.1	21.1	NPL	19.7	3.3
Banfield Freeway-II	3161	3900	3793	3900	530/178**	1107/163**	628	657	22.7	21.4	20.9	20.9	3.3
I-95 Miami-I	6145	7200	6416	7200	170	309	274	314	36.9	34.5	33.4	31.3/ 32.9*	7.5
I-95 Miami-II	5170	7200	5880+	7200	1246/ 309**	1357/ 246**	314	352	34.5	34.7	31.3/ 32.9*	31.3/ 32.9*	7.5
Southeast E-way(1977)	5504	7000	4306	5300	388	641	2000	2124	35	43	NPL	25.0	8.
Southeast E-way(1971)	4554	5300	4201	5300	NPA	NPA	2152	2454	35	30.5	NPL	23.0	8.4
I-495, Lincoln Tunnel	2324	5200	3227	5400	NPA	NPA	21868	26092	70	68	NPL	60	2.5

Table continued on following page.

Table 5 (Continued)

SUMMARY OF KEY DATA FOR HOV FREEWAY SITES

	HOV Time Advantage (After)	Nonpriority WIVTT	Priority WIVTT	Speed (MPH)				One-Way Average Trip Length (Miles)	Number of Buses per Hour	
				General Purpose Before	Purpose After	HOV Before	HOV After		Before	After
Shirley Highway	20.0	+ 2.1	-17.9/+0.8*	19.0	17.7	55.5	51.5	12.4	176	194
San Bernardino-I	8.4	+ 0.5	- 7.9	25.4	24.7	NPL	49	19.8	10	45
San Bernardino-II	10.8	+ 0.4	-10.4	24.2	23.6	49	55/49*	19.8	81	81
U.S. 101-I	2.8	0	- 2.8	30.0	30.0	NPL	47.1	16	86	94
U.S. 101-II	0.9	- 1.9	- 2.8	30.0	40.0	47.1	47.1	16	94	97
Banfield Freeway-I	1.4	0	- 1.4	38	37.9	NPL	51.5	7	10	20
Banfield Freeway-II	0.5	- 1.3	- 1.8	33	42	47	46.7	7	20	22
I-95 Miami-I	3.2/1.6	- 2.4	- 5.6/-0.5*	33.2	40.2	44.7	56.6/46.7	15.7	10	10
I-95 Miami-II	3.4/1.8	+ 0.2	- 3.2	40.2	39.4	56.6/46.7	56.6/46.7	15.7	10	10
Southeast E-way(1977)	18	+ 8.0	-10.0	21.0	15.5	NPL	37.2	15	50	54
Southeast E-way(1971)	7.5	- 4.5	-12.0	23	29	NPL	50.4	15	57	65
I-495, Lincoln Tunnel	8.0	- 2.0	-10.0	10	11.5	NPL	30	25	497	597

NPA = No priority automobiles included in HOV treatment.
Numbers not rounded off to significant digits.

NPL = No priority lane.

*Priority Auto/Priority Bus.

**Two-occupant/three-occupant carpool.

†High violation rate.

SOURCE: Charles River Associates.

Table 6

HOV TREATMENT FOR BEFORE AND AFTER TIME PERIODS

<u>HOV Facility</u>	<u>Before Period</u>	<u>After Period</u>
Shirley Highway	Bus only	4+ vehicles added
San Bernardino-I	No priority	Bus only
San Bernardino-II	Bus only	3+ vehicles added
U.S. 101-I	No priority	Bus only
U.S. 101-II	Bus only	3+ vehicles added
Banfield Freeway-I	No priority	3+ vehicles + buses
Banfield Freeway-II	Buses/3+ vehicles	2+ vehicles added
I-95 Miami-I	Bus (on NW 7th Ave)	Buses/3+ vehicles added to I-95
I-95 Miami-II	Buses/3+ vehicles	2+ vehicles added
Southeast Expressway (1977)	No priority	Buses/3+ vehicles
Southeast Expressway (1971)	No priority	Bus only
I-495, Lincoln Tunnel	No priority	Bus only

Table 7

IMPLEMENTATION DATE AND DATES OF BEFORE AND AFTER
TIME PERIODS FOR FREEWAY HOV FACILITIES

HOV Facility	HOV Implementation Date	Date of Data Collection	
		Before Period	After Period
Shirley Highway	December 10, 1973	10/73 11/73 (speeds)	10/74 11/74 (speeds)
San Bernardino-I	January 29, 1973 (partial)	<1/29/73	10/73 (bus)
	July 15, 1973 (El Monte Terminal)	4/73 (speeds)	11/73 (auto)
San Bernardino-II	October 25, 1976	10/76	4/77 (Vol.) 2/77 (speeds)
U.S. 101-I	December 20, 1974	9-11/74	9-11/75
U.S. 101-II	June 15, 1976	9-11/75	9-11/76
Banfield Freeway-I	December 15, 1975	4-6/75	4-6/77
Banfield Freeway-II	February 12, 1979	8/78-2/79	9/79-1/80
I-95 Miami-I	March 15, 1976	8/74-3/76	3/76-1/77
I-95 Miami-II	January 10, 1977	3/76-1/77	1/77-5/77
Southeast Expressway (1977)	May 4, 1977	3/77	10/77
Southeast Expressway (1971)	May 24, 1971	"Before"	"During"
I-495, Lincoln Tunnel	December 18, 1970	10/70	4/71

SOURCE: Charles River Associates.

Phase II, U.S. 101 Phase II, and I-95 Phase I) represent a change in the HOV facility from bus-only to mixed-mode (carpools and bus) operation. Finally, the Banfield Freeway Phase II and Miami I-95 Phase II involved allowing 2+ person carpools onto an existing bus and 3+ person carpool lane.

DATA LIMITATIONS

The data presented in the evaluation reports for the various HOV sites were not always consistent with the reporting format established for the worksheets. Therefore, it was sometimes necessary to make adjustments or estimates from the data presented, if no other information was available. The following sections describe when calculations were typically required and, if necessary, the assumptions that were made. The basic objective, however, was to use and report the data as originally stated for each HOV facility.

TRAVEL VOLUMES

Auto and transit volumes were frequently presented in the evaluation reports for the full a.m. and/or p.m. peak period. Therefore, to obtain an estimate of the peak one-hour volumes, the volumes for the peak period were divided by typical peaking factors.

AVERAGE TOTAL TRIP LENGTH

Average trip length was required in some instances to determine average total travel time. When information on trip length was not presented in a report, the agency or organization in charge of the facility was contacted to determine whether the information was available from other sources. In one instance, Census information on trips made to the CBD from different zones in the study corridor was used.

TOTAL TRAVEL TIMES

For almost every site, information was available on the change in travel time on both the general purpose and HOV lanes due to the implementation of the HOV project. This information was very useful in determining the before and/or after total travel times if this information was not otherwise available. For example, if a total travel time estimate was available for the before period, but not the after period, the data on travel time change was used to estimate total travel time for the after period. When neither the before or the after travel time was reported, an estimate of one value was made using average trip length and speed, and the value for the second time period was computed using the known change in travel time.

This concludes the discussion on the data available describing before-and-after conditions for HOV facilities across the United States. Chapter 4 presents the results of the models that were estimated from the data collected on freeway HOV facilities.

4

MODEL DEVELOPMENT AND TESTING

This chapter includes three main sections. The first describes the development and estimation results of the various demand models that are used in the worksheets to predict travel volumes. The second section discusses the supply model that is needed in certain circumstances for equilibration. In the third section, the results of tests made with the new HOV worksheets are presented and compared to similar forecasts obtained from the Pivot Point Logit Model.

DEMAND MODEL SPECIFICATION AND FUNCTIONAL FORMS

This section discusses the initial hypotheses concerning demand model forms and variable specifications as constrained by the before-and-after data collected and described in Chapter 3. The results of the demand model estimation phase are also presented in this section.

The first consideration addressed was the specification of the (dependent) variable being forecast, that is, whether travel volumes for each mode should be expressed in terms of person or vehicle volumes. The advantage of using persons is that one can examine directly the peak hour person throughput of a given freeway for different types of HOV strategies. However, the major drawback of this approach is in travel equilibration on the general purpose lanes, since highway supply relationships are expressed in terms of vehicles. Consequently, it was decided to use vehicles per hour as the measure of travel volumes for various classifications of autos, but use person trips for bus transit, since equilibration is not an issue in predicting bus demand.

Initially, the demand models included as independent variables relative and absolute travel time changes for the mode being forecasted as well as for competing modes. The nonpriority auto model also contained a term to reflect the change in available "capacity" on the general purpose lanes, resulting from the particular HOV strategy being examined. (More details on these variables are provided later in this section.)

For each mode (nonpriority auto, priority-eligible auto or carpool, and HOV bus), models were estimated based on both linear (i.e., $\sum a_i X_i$) and product (i.e., $\pi a_i X_i$) specifications of the independent variables. In addition, volumes and level-of-service variables were entered using either absolute differences (i.e., $X_1 - X_0$) or relative differences or changes (i.e., $(X_1 - X_0)/X_0$) in the dependent and independent variables. Although one functional form did not dominate the others for all HOV sites, the model form that produced the most favorable results for all modes can be expressed as:

$$\frac{V_1^m - V_0^m}{V_0^m} = a_0 + \sum_i a_i \frac{(T_1^i - T_0^i)}{T_0^i} \quad (1)$$

where:

V_0^m = peak hour before volume for mode m;

V_1^m = peak hour after volume for mode m;

T_0^i = before travel times for modes i to m;

T_1^i = after travel times for modes i to m; and

$a_{0,i}$ = calibration coefficients.

The following section presents the results of travel demand models estimated using Equation (1) for the nonpriority auto, priority auto, and priority bus modes.

NONPRIORITY AUTO MODEL

Table 8 presents the parameter estimates, "t" statistics, and associated regression results for the nonpriority auto model. All signs for the parameter estimates are correct and all are significant at the appropriate levels. The R^2 for the entire model is 0.98, with an F-ratio significant at the 99 percent level.

TABLE 8

NONPRIORITY AUTO MODEL: REGRESSION RESULTS

<u>Variable</u>	<u>Parameter Estimate</u>	<u>t-Statistic</u>	<u>Level of Significance</u>
Constant	-0.916	-10.5	.01
NPA-TT	-1.053	-3.3	.01
PA2-TT	+1.190	+3.5	.01
PA3/4-TT	+0.122	+1.4	.10
Bus-TT	+0.278	+3.8	.01
EFCTR	+0.949	+12.1	.01

F-Ratio = 53.1
 Significance = .01
 R^2 = .98

Legend

NPA-TT = Percent change in total travel time for nonpriority autos

PA2-TT = Percent change in total travel time for 2-person priority autos

PA3/4-TT = Percent change in total travel time for 3/4+ person priority autos

Bus-TT = Percent change in total travel time for buses

EFCTR = Eligibility Factor

SOURCE: Charles River Associates.

A generalized least squares estimation procedure was used for model estimation. Basically, this entails multiplying all variables for each site by the square root of the sum of the before and after travel volumes. This procedure is necessary because of the large differences in the magnitude of the dependent variables (i.e., travel volumes) between sites. Not to use this procedure would result in the size of the sample variance for each site being proportional to the magnitude of each observation. However, by using the generalized least squares procedure, more efficient (i.e., tighter variances) econometric estimates are obtained.

The variable NPA-TT in Table 8 represents the percent change in total travel

time for nonpriority autos (i.e., $(T_1^{npa} - T_0^{npa})/T_0^{npa}$). Similarly, PA2-TT is the percent change in travel time for 2-person priority autos. If 2-person carpools are not allowed onto the HOV lanes, this variable will take on a value of zero. The same is true for PA3/4-TT, which is the percent change in total travel time for 3+ or 4+ person carpools that are already on, or will be allowed on, the HOV lanes. Bus-TT is the percent change in total time for buses that are already on, or will be allowed on, the HOV lanes. The variable, EFCTR, (for eligibility factor) reflects the percentage change in "capacity" on the general purpose lanes made available in the after period for use by nonpriority autos. The variable is computed as follows:

$$EFCTR = \frac{L_1^{GP}}{L_0^{GP}} \cdot \frac{V_0^{npa} + V_0^{Pa} + 2B_0^{Peb}}{V_0^{npa}}$$

where:

L_0^{GP} = number of general purpose lanes in the before period;

L_1^{GP} = number of general purpose lanes in the after period;

V_0^{npa} = peak hour volume of nonpriority autos in the before period;

V_0^{Pa} = peak hour volume of priority-eligible autos in the before period;
and

B_0^{Peb} = number of buses eligible to move to HOV lanes.

If no autos (carpools) or buses are allowed to move to the HOV lane, and the number of general purpose lanes does not change, EFCTR will equal 1.0. If, for example, 10% of the total number of autos using the general purpose lanes in the before period become eligible to use the HOV lanes, EFCTR will equal 1.11. If one of 4 general purpose lanes is "taken away" for HOV use, the value of EFCTR will be reduced to 75% (i.e., $3 \div 4$) of its value if the lane were not taken away. Thus, this variable controls for site-to-site differences in the composition of vehicles in the before period that become

eligible to use an HOV facility in the after period. In addition, the variable reflects the major supply effects due to taking away a general purpose lane for use by HOV vehicles.

PRIORITY AUTO MODEL

Table 9 presents the parameter estimates, "t" statistics, and associated regression results for the priority auto models that were obtained using a generalized least squares estimation procedure. All parameter estimates have the correct sign and all are significant; (PA2-TT is, however, only significant at the .12 or 88% level). The variables PA2-TT and PA3-TT represent the respective percent change in total travel times for 2 or 3/4 person automobiles that are already on or will be allowed onto the HOV facility. Thus, the model(s) shown in Table 9 can be used to forecast volumes for carpools already on the HOV facility or that will become eligible to use the facility in the after period.

If the model is being used to forecast the number of 3+ person carpools that will be using the HOV lanes, the variable PA2-TT x [Q] is deleted (or set equal to zero). This is accomplished by setting "Q" equal to zero. Conversely, if the model will be used to forecast the volume of 2-person priority eligible automobiles, the variable PA3-TT is set equal to zero. (Note: This model cannot be used to forecast the volume of 2 or 3/4 person carpools that will be traveling on the general purpose lanes in the after period.)

Since the coefficient of the 3/4 person travel time variable is larger than that for 2-person carpools, the model indicates that allowing 3+ person carpools onto the HOV lanes will lead to a larger percentage increase in the volume of 3+ person carpools relative to the percentage increase in 2+ person carpools if these are granted access to the HOV facility. (Note that while this is true in percentage terms it may not always be true in absolute terms, since the volume of 2-person autos is usually much greater than the volume of 3-person autos.)

The magnitude of both carpool travel time coefficients (which are related to direct travel time elasticities) are much larger than those derived from traditional or contemporary mode choice studies. The reason for this is that the priority auto model is capturing the effects of trip generation, time of day, and route diversion changes as well as modal choice decisions. Thus, a model that examined only mode choice effects would seriously underpredict the actual volume of carpools on the HOV facility.

The variable Bus-TT is the percentage change in bus travel time between the before and after period. Note that its magnitude is about two-thirds the size of the carpool travel time coefficients. If buses are already on the HOV facility and the policy being examined is to allow carpools onto the facility, the value of this variable will normally take on a value of zero

TABLE 9

PRIORITY AUTO MODEL: REGRESSION RESULTS

<u>Variable</u>	<u>Parameter Estimate</u>	<u>t-Statistic</u>	<u>Level of Significance</u>
Constant	-0.2	-0.6	.28
PA2-TT x [Q]	-6.7	-1.3	.12
PA3/4-TT x [1-Q]	-7.7	-4.1	.01
Bus-TT	+4.8	+2.3	.03

F-Ratio = 8.1
 Significance = .02
 R^2 = .87

Where:

Q = 1 for 2-person priority autos
 Q = 0 for 3/4 person priority autos.

Legend

PA2-TT = Percent change in total travel time for 2-person priority autos

PA3/4-TT = Percent change in total travel time for 3/4+ person priority autos

Bus-TT = Percent change in total travel time for buses

SOURCE: Charles River Associates.

(assuming, as is typically the case, no degradation in travel speeds on the HOV facility), and the percentage change in the volume of carpools will be a function of the percent change in carpool travel times. However, if buses and carpools are being granted the use of the HOV facility at the same time (i.e., the facility did not exist in the before period), then the model indicates that the percentage increase in carpool volume will be about one-third less compared to the case in which carpools only were granted access. Again, this appears appropriate, as the bus mode will also be competing for some of the travelers who may wish to use the HOV facility.

PRIORITY BUS MODELS

After considerable testing and evaluation of alternative specifications for the priority bus model, it was determined that the most appropriate procedure for modeling changes in bus ridership is to use different variable specifications, depending upon whether buses and/or carpools are allowed onto the HOV lanes and whether bus supply is determined exogenously or endogenously. A single model specification does not adequately explain the change in transit ridership for both bus-only and bus/carpool strategies. This is because the percent change in bus travel time is an important explanatory factor of bus ridership change when only buses are allowed onto the HOV facility, whereas changes in carpool travel times tend to be more random in nature. Conversely, when carpools are allowed onto an HOV facility that buses are already using, bus travel times typically do not change, and thus have little explanatory power. Carpool travel times, on the other hand, do change, and through competition effects have an influence on transit ridership.

Table 10 presents the parameter estimates, "t" statistics, and associated regression results for the priority bus models that were estimated using a generalized least squares estimation procedure. As indicated in the table, Model A is used when only buses will use the HOV lane and bus supply is determined endogenously or as a direct result of the HOV time savings. The one variable that was found to be significant was Bus-TT, the percentage change in bus travel time. In effect, what the estimation process revealed was that other factors, such as changes in nonpriority auto travel time, or even secular transit growth rates (which would show up in a constant term) have little or no explanatory power compared to bus travel time changes. Because of the small sample size, however, the coefficient estimate is only significant at the 83 percent level.

Model B is used when only buses will use the HOV lane and supply is determined exogenously or apart from the ridership change expected just from the HOV time savings; (e.g., for the San Bernardino-Phase I Project, the El Monte bus terminal was constructed and, in the after period, the number of buses per hour was increased by 350% from 10 to 45). The two variables, percent change in bus travel time and percent change in the number of peak hour buses, have the correct sign and are significant at appropriate levels.

TABLE 10

PRIORITY BUS MODELS: REGRESSION RESULTS

<u>Model #</u>	<u>Variable</u>	<u>Parameter Estimate</u>	<u>t-Statistic</u>	<u>Level of Significance</u>
A	Bus-TT	-1.404	-1.1	.17
B	Bus-TT	-0.308	-2.3	.07
	Bus-No.	+0.422	26.7	.01
C/D	Constant	+0.227	1.2	.14
	PA2-TT x [Q]	+0.435	0.5	.30
	PA3/4-TT x [1-Q]	+1.710	0.5	.30

	<u>Model A</u>	<u>Model B</u>	<u>Model C/D</u>
F Ratio =	1.2	505.1	1.1
Significance =	.35	.01	.46
R ² =	.28	.99	.44

Legend

A = Bus only on HOV lane (supply determined endogenously)

B = Bus only on HOV lane (supply determined exogenously)

C = Bus and 3+/4+ person carpools on HOV lane (Q = 0)

D = Bus and 2+ person carpools on HOV lane (Q = 1)

Bus-TT = Percent change in total travel time for buses

Bus-No. = Percent change in the number of peak hour buses

PA2-TT = Percent change in total travel time for 2-person priority autos

PA 3/4-TT = Percent change in total travel time for 3/4+ person priority autos

SOURCE: Charles River Associates.

(The bus supply variable, "Bus-No," representing the percent change in the number of peak hour buses, was not used in the other models because of the concern for simultaneity. This occurs because bus supply is highly correlated with the dependent variable, bus passengers.)

Model C has a constant and a term for the percent change in total travel time for priority autos with 3 or 4-person occupancies. Consequently, this model is used when buses and 3 or 4-person carpools are allowed onto the HOV lane. Model D has the same constant, but uses the percent change in travel time for 2-person priority autos to forecast the volume of bus passengers when buses and 2-person carpools will be using the HOV lane. While the signs for all variables are correct, the significance levels are lower (70%) than typically desired. Thus, the higher standard errors for these coefficients imply greater variances in the forecast of percent change in bus riders. However, in many instances, the percent change in bus ridership is relatively small (especially compared to changes in carpools), thus partially negating the effects of these larger variances.

Unlike auto and carpool volumes, changes in the volume of bus users are more likely to be dependent on many more site-specific characteristics in addition to changes in level of service (as represented by total travel time changes). Some of these other factors, which are difficult to incorporate in a sketch planning model, would include: average bus headways, average waiting and transfer times, characteristics of bus area coverage or route network, and provision of fringe parking lots for park-and-ride express bus service. Thus, the analyst is reminded that while the priority bus models should provide reasonable forecasts that reflect average conditions observed at other HOV sites, the results may not be the most applicable to the HOV facility being evaluated. In such instances, more complex procedures may be required to predict ridership on HOV buses.

SUPPLY MODEL DEVELOPMENT

In order to forecast demand, it is necessary to quantify what changes will occur in supply. A demand model with very stable and reliable coefficients may not provide realistic forecasts if good information cannot be obtained on the changes in level of service (in particular, travel times) that are needed to drive the model. Thus, an algorithm or set of supply relationships is required.

For the 12 HOV data sets used in developing the demand models, it was observed that traffic on the general purpose lanes in the before period was either operating at or very near capacity (service level E) or, more commonly, under force-flow conditions (service level F). One of the key questions of interest is whether (and how) these service levels will change, given the implementation of a particular HOV strategy. By analyzing before-and-after service levels for various HOV freeway facilities, it was

determined that force-flow conditions continued in the after period when: 1) a general purpose lane was taken away; or 2) the number of general purpose lanes did not change, but a bus-only HOV lane was implemented. When the number of general purpose lanes remained the same and carpools were allowed onto the HOV lane(s), traffic on the general purpose lanes either continued operating under force-flow conditions, or began operating under free-flow conditions. These observations, therefore, can be incorporated into a straightforward procedure for computing supply changes due to various HOV strategies on freeways.

Commensurate with the level of detail of the demand models, a supply model was developed to estimate average running speed and thus travel time changes for different volume levels (and possibly capacity changes) on the general purpose lanes. The model was based on the BPR/FHWA speed-volume relationship normally used in traffic assignment models.* This relationship can be expressed in general terms as:

$$T_1 = T_0 [1 + a(V/C)^b] \quad (3)$$

where:

T_1 = travel time in time period 1;

T_0 = travel time at zero volume (or under free-flow conditions);

V = highway traffic volume;

C = capacity of highway; and

a, b = model coefficients.

Expressed in terms of speed, the above equation can be written as:

$$S_1 = \frac{S_0}{1 + a(V/C)^b} \quad (4)$$

In this relationship, the coefficient "a" has a significant influence on the calculated travel speed when demand exactly equals capacity ($V = C$). For example, if S_0 is assumed to equal 60 mph, setting "a" equal to 1.0 will result in a S_1 speed of 30 mph when $V/C = 1$. Similarly, setting "a" equal to 1.5 will result in a S_1 speed of 40 mph. Note that the speeds at capacity are not affected by the values of the coefficient "b."

*See Federal Highway Administration, Urban Transportation Planning: General Information, March 1972, pp. III-15.

The "b" coefficient, on the other hand, determines the shape of the "S" curve, or, in other words, the sensitivity of changes in speed to changes in V/C. Figure 1 illustrates how different values for the coefficient "b" can be used to reflect different assumptions (or differences in local characteristics) in the relationship between speed and V/C. In particular, the 1965 HCM (Figure 9.1, p. 264) indicated that speeds decrease almost linearly as V/C (under free-flow conditions) increases from 0 to 0.9. However, more recent information presented in Transportation Research Circular 212 (Figure 1.5, p. 160) and observed in empirical studies* indicates that speeds are nearly constant on multilane freeways as V/C increases from 0 to 0.9, but decrease rapidly for values of V/C greater than 0.9. Thus, the supply relationship given in the worksheets have set "b" equal to 15.0 and "a" equal to 1.0. However, the analyst should feel free to modify these coefficient values if local conditions warrant.

For comparison purposes, the dash line (and equations) shown in Figure 1 illustrate traffic operations under force-flow conditions. As stated above, travel flows on the general purpose lanes typically operated under force-flow conditions in the before period. However, those sites that achieved free-flow operations in the after period did so at approximately the same V/C ratio that existed in the before period. Of course, peak hour speeds increased -- typically on the order of 10 mph. Conversely, those sites where force-flow conditions persisted operated at nearly the same speed and V/C ratio in the after period.

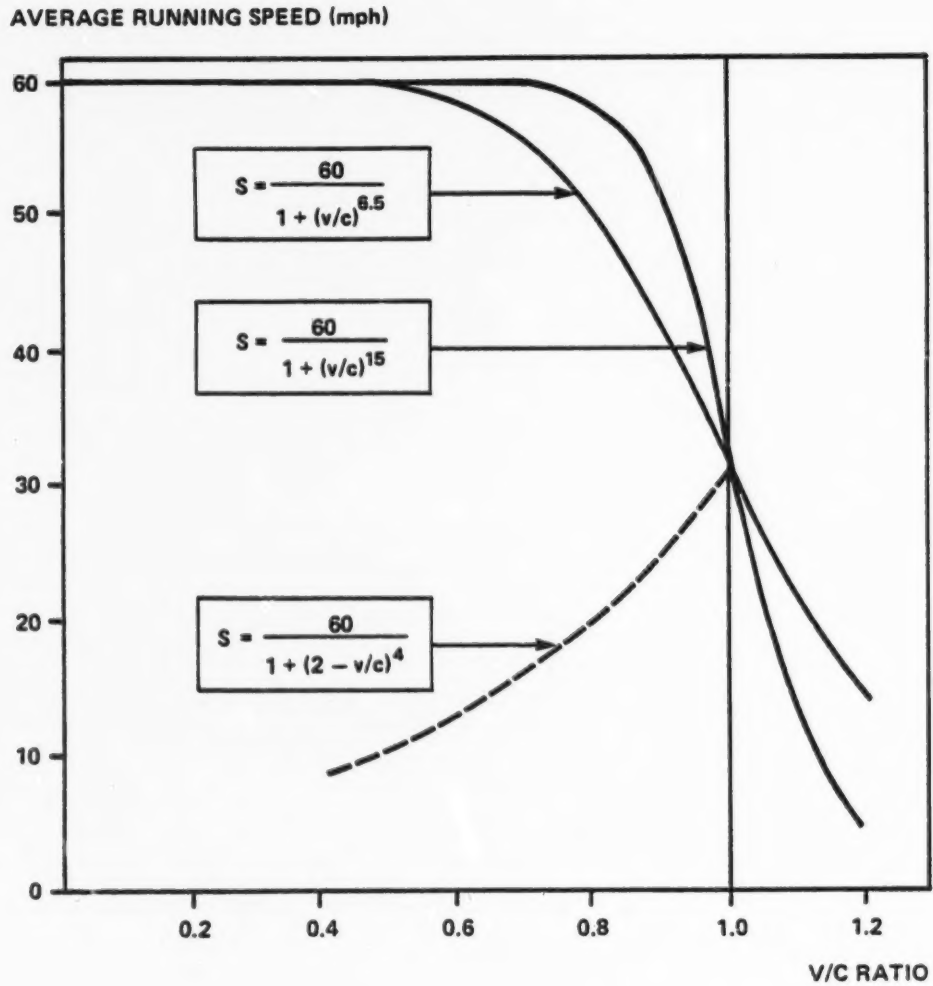
Given these empirical patterns observed at various HOV sites, a strategy for modeling supply and determining equilibrium has been developed. First, based on the HOV strategy being evaluated, it is determined whether free-flow conditions could exist on the general purpose lanes. If the answer is no, then the existing general purpose lane speeds are used in the after period. If the answer is yes, then the before V/C ratio is used in Equation (4) to estimate free flow speeds and travel times. These travel times are used to forecast auto volumes on the general purpose lanes. A check is made to compare these predicted volumes to capacity. For V/C ratios greater than 1.0, it is assumed that force-flow conditions will exist. Thus, travel times are revised and new volumes computed. Alternatively, the new V/C ratio is used in Equation (4) to determine a revised speed and travel time and, through this iterative procedure, a new volume estimate is obtained.

When using the latter approach, it is possible that each subsequent iteration will lead to a better estimate of equilibrium volumes. However, it is also possible that they may not. When this happens, equilibrium travel speed (and thus volumes) can be obtained by plotting the demand curve (from two or more iterations of volumes and speeds from the demand model), and the supply curve (from two or more iterations of speeds and volumes obtained from the supply model), as well as computing the speed (and thus volume) at which the two curves intersect.

*William A. Stock, Richard C. Blankenhorn, and Adolf D. May, The FREQ3 Freeway Model. Report 73-1, Institute of Transportation and Traffic Engineering, University of California, June 1973, p. 32.

Figure 1

ALTERNATIVE RELATIONSHIPS BETWEEN V/C RATIO
AND OPERATING SPEED



MODEL TESTING AND COMPARISONS

This section compares the results of forecasts obtained using the HOV modeling worksheets developed during this study with those obtained using the Pivot Point Logit Model. For consistency, forecasts are obtained using known level-of-service changes based on the actual before-and-after data given in Chapter 3 (see Table 5). However, in the case of the HOV worksheets, forecasts are also presented using only before data.

HOV MODEL

Forecasts of peak hour volumes were made employing the HOV worksheets developed during this study (see Appendix A in "User's Guide") and using as input data known service level changes. For each site the forecasts are compared to actual volumes for the after period, and a relative error or difference is computed and listed in Table 11. Also given in the table are the average relative errors across all sites for the three modes. It is readily apparent that average errors and standard deviations are quite small for both the nonpriority auto and HOV bus modes. Like the results for the Pivot Point Logit Model that are presented in the following section, the largest errors occurred for the priority-granted carpool mode. However, the average error is much smaller, only -7.7%, while the standard deviation is about the same (34.9%). Of course, more reliable forecasts are to be expected, since the model coefficients were estimated using the same before-and-after data used in forecasting. Even so, the model is able to capture other effects in addition to shifts between modes. Clearly, this is a decided advantage, given the importance of time-of-day and route diversion impacts.

In order to test the demand, supply, and equilibration components of the HOV worksheets, forecasts were also made using only before data for each HOV site. (The one exception was to use the after number of buses for the San Bernardino-I site, as it was felt that the increase in supply was determined exogenously.) The forecasts and relative percent errors are given in Table 12. The average errors increased slightly for the nonpriority auto and priority bus modes, but by a somewhat larger amount for the priority auto mode.

The relatively higher standard deviations for the priority auto or carpool forecasts (as given in both Tables 11 and 12) indicate that other factors (either measurable, site-specific, or unobservable) in addition to those included in the model may influence the volume of carpools on the HOV facility. As discussed earlier, a lack of information describing the before-and-after characteristics of alternative highways in the HOV corridor prohibited a systematic examination of these effects within the context of this study. The tests reported above, however, clearly illustrate that the worksheets can be used to provide a very reasonable examination of travel flows due to implementing alternative HOV strategies on freeways.

Table 11
COMPARISON OF HOV WORKSHEET PREDICTIONS TO ACTUAL TRAVEL VOLUMES
(Using Actual Level-of-Service Changes)

HOV Facility	Nonpriority Auto Volumes			Relative Error (P-A)/A	Priority Auto Volumes			Relative Error (P-A)/A	HOV Bus Ridership			Relative (P-A)/A
	Actual Before	Actual After	Predicted After		Actual Before	Actual After	Predicted After		Actual Before	Actual After	Predicted After	
Shirley Highway	4,896	5,126	5,105	- 0.4	195	758	652	-13.9	7,900	8,756	8,595	- 1.8
San Bernardino-I	7,300	7,300	7,221	- 1.1	NPA	NPA	NPA	--	402	1,017	1,018	+ 0.1
San Bernardino-II	7,067	7,277	7,394	+ 1.6	299	576	761	+32.1	2,490	2,708	2,807	+ 3.7
U.S. 101-I	5,314	5,330	5,533	+ 3.8	NPA	NPA	NPA	--	3,370	3,572	3,740	+ 4.9
U.S. 101-II	5,125	5,333	5,399	+ 1.2	205	288	289	+0.4	3,572	3,686	4,257	+15.5
Banfield Freeway-I	3,713	3,845	3,790	- 1.4	37	180	37	-79.4	340	570	407	-28.6
Banfield Freeway-II	3,161	3,793	3,659	- 3.5	708	1,180	846	-28.1	628	657	685	+ 4.3
I-95 Miami-I	6,145	6,416	6,332	- 1.3	170	309	321	+ 4.0	274	314	319	+ 1.3
I-95 Miami-II	5,170	5,880	5,919	+ 0.7	1,555	1,603	2,013	+25.6	314	352	335	- 4.7
Southeast Xway (1977)	5,504	4,306	4,269	- 0.8	388	641	629	- 1.9	2,000	2,124	2,205	+ 3.8
Southeast Xway (1971)	4,554	4,201	4,226	+ 0.6	NPA	NPA	NPA	--	2,152	2,454	3,188	+29.9
I-495, Lincoln Tunnel	2,324	3,227	3,234	+ 0.2	NPA	NPA	NPA	--	21,860	26,092	26,254	+ 0.6
Average Error (standard deviation)				- 0.93% (1.8%)				- 7.7% (34.9%)				+ 2.4% (13.4%)

NPA = No priority automobiles included in HOV treatment.

SOURCE: Charles River Associates.

Table 12
COMPARISON OF HOV WORKSHEET PREDICTIONS TO ACTUAL TRAVEL VOLUMES
(Using Only Before Data)

HOV Facility	Non Priority Auto Actual		Volumes Predicted After	Relative Error (P-A)/A	Priority Auto Actual		Volumes Predicted After	Relative Error (P-A)/A	Actual		Predict- After	Relative (P-A)/A
	Before	After			Before	After			Before	After		
Shirley Highway	4,896	5,126	5,045	-1.6	195	758	654	-13.7	7,900	8,756	8,550	-2.4
San Bernardino-I	7,300	7,300	7,195	-1.4	HPA	HPA	HPA	--	402	1,017	1,024	+0.7
San Bernardino-II	7,067	7,277	7,415	+1.9	299	576	680	+18.0	2,490	2,708	2,846	+5.1
U.S. 101-I	5,314	5,330	5,512	+3.4	HPA	HPA	HPA	--	3,370	3,572	3,780	+5.8
U.S. 101-II	5,125	5,333	5,438	+1.9	205	288	289	+0.3	3,572	3,686	4,258	+15.5
Banfield Freeway-I	3,713	3,845	3,822	-0.6	37	180	46	-74.4	340	570	490	-14.0
Banfield Freeway-II	3,161	3,793	3,662	-3.5	708	1,180	846	-29.3	628	657	685	+ 4.3
I-95 Miami-I	6,145	6,416	6,864	+7.0	170	309	259	-16.2	274	314	325	+ 3.5
I-95 Miami-II	5,170	5,880*	6,347	+7.9	1,555	1,603	1,500**	--	314	352	335	- 4.8
Southeast Xway (1977)	5,504	4,306	3,909	-9.2	388	641	737	+15.0	2,000	2,124	2,124	0.0
Southeast Xway (1971)	4,554	4,201	4,384	+ 4.4	HPA	HPA	HPA	--	2,152	2,454	3,170	+29.2
I-495, Lincoln Tunnel	2,324	3,227	3,253	+0.8	HPA	HPA	HPA	--	21,868	26,092	26,561	+ 1.8
Average Error (standard deviation)				-0.9% (4.7%)				-13.9% (31.3%)				+ 3.7% (10.6%)

Notes on following page.

Table 12 (Continued)
COMPARISON OF HOV WORKSHEET PREDICTIONS TO ACTUAL TRAVEL VOLUMES
(Using Only Before Data)

Notes:

NPA = No priority automobiles included in HOV treatment.

*High violation rate.

**Model predicts saturated HOV lane conditions.

SOURCE: Charles River Associates.

PIVOT POINT LOGIT MODEL

Forecasts were made using the Pivot Point Logit Model worksheets and accompanying coefficients contained in the FEA report entitled "Guidelines For Travel Demand Analyses of Program Measures to Promote Carpools, Vanpools, and Public Transportation" (see Chapter 2 for additional information on this model). Because the Pivot Point Logit Model "pivots" about mode shares determined on the basis of person trips, it was necessary to begin working from before-and-after peak hour person trips (rather than vehicle trips) by mode for each site. For most HOV sites, this information was obtained for single passenger auto, two-person carpools, three-or-more person carpools, and bus. Besides allowing computation of before-and-after mode shares, this information also yields the combined peak hour person throughput on the HOV and general purpose lanes.

For purposes of applying the model, all persons on the facility were grouped into one market segment. In effect, all individuals are assigned travel characteristics and changes in level of service that reflect the average of the variables (i.e., travel times and changes in travel times). Also, since data were only collected on a.m. peak hour travel, it was assumed that this information could be used to infer round-trip travel behavior and round-trip changes in level of service when applicable. (This was true for all sites except I-495 Lincoln Tunnel and Southeast Expressway 1977, since the HOV lane did not operate in the evening peak hour on these two facilities.)

The mechanics of applying the model require the use of a hand-held or desk-top calculator (with appropriate capacity for algebraic functions, such as that provided by an exponential key) and attention to detail. The apparent simplicity of the step-by-step calculations required can easily lead to, and disguise, a relatively simple error or miscalculation, resulting in revised mode shares that may seem plausible.

Given that the essential data elements had already been tabulated, each application of the model required about 2-3 hours to undertake. The actual calculations performed, however, take no more than 15-20 minutes. Most of the time is spent in preparing the data in its final form (i.e., from the data that has already been obtained) and rechecking the calculations.

The predicted and actual mode shares for each site are presented in Table 13 along with a comparison of the absolute (predicted modal percent - actual modal percent) and relative $((\text{predicted} - \text{actual}) \div \text{actual})$ errors. In evaluating the model forecasts, one of the limitations of this type of model (and in fact all "share" models) is readily apparent; the model can only predict changes in mode shares and not changes in total person trips on the facility. Yet as shown in Table 13, almost all sites experienced an increase in total person trips in the after period compared to the before period. (For the two exceptions, exogenous factors contributed to the decline in the number of trips on the facility.)

Table 13

COMPARISON OF PIVOT POINT MODEL PREDICTIONS TO ACTUAL MODE SHIFTS
(Using Actual Level-of-Service Changes)

HOW Facility	Mode	Before Period		Actual After Period		Predicted Share-Percent (P)	Absolute Error (P-A)	Relative Error (P-A)/A
		Persons	Share-Percent (B)	Persons	Share-Percent (A)			
Shirley Highway	Auto (N.P.)	6414	42.3	6992	36.6	39.6	+ 3.0	+ 8.2
	4+ Carpool	860	5.6	3343	17.5	9.5	- 8.0	-45.7*
	Bus	7900	52.1	8756	45.9	50.8	+ 4.9	+10.7
		15174		19091				
San Bernardino-I	Auto	6110	66.9	6110	62.7	66.0	+ 3.3	+ 5.3
	2 Person	2014	22.0	2014	20.7	21.8	+ 1.1	+ 5.3
	3+ Person	609	6.7	609	6.2	6.6	+ 0.4	+ 6.5
	Bus	402	4.4	1017	10.4	5.6	- 4.8	-46.2*
		9135		9750				
San Bernardino-II	Auto	5980	51.4	6162	47.3	49.5	+ 2.2	+ 4.7
	2 Person	2174	18.7	2230	17.1	18.2	+ 1.1	+ 6.4
	3+ Person	996	8.6	1918	14.8	11.4	- 3.4	-23.0*
	Bus	2490	21.4	2708	20.8	20.8	0	0
		11640		13018				
U.S. 101-I	Auto	4029	39.3	3979	37.7	38.2	+ 0.5	+ 1.3
	2 Person	2196	21.5	2292	21.7	20.9	- 0.8	- 3.7
	3+ Person	644	6.3	708	6.7	6.1	- 0.6	- 9.0
	Bus	3370	32.9	3572	33.9	34.9	+ 1.0	+ 2.9*
		10239		10551				
U.S. 101-II	Auto	3979	37.7	4225	38.1	38.4	+ 0.3	+ 0.8
	2 Person	2292	21.7	2216	20.0	20.6	+ 0.6	+ 3.0
	3+ Person	708	6.7	970	8.7	8.4	- 0.3	- 3.4*
	Bus	3572	33.9	3686	33.2	32.5	- 0.7	- 2.1
		10551		11097				

Table continued on following page.

Table 13 (Continued)

COMPARISON OF PIVOT POINT MODEL PREDICTIONS TO ACTUAL MODE SHIFTS
(Using Actual Level-of-Service Changes)

HOV Facility	Mode	Before Period		Actual After Period		Predicted Share-Percent (P)	Absolute Error (P-A)	Relative Error (P-A)/A
		Persons	Share-Percent (B)	Persons	Share-Percent (A)			
Banfield Freeway-1	Auto	2978	60.6	3145	56.0	59.7	+ 3.7	+ 6.6
	2 Person	1470	30.0	1400	24.9	29.5	+ 4.6	+18.5
	3+ Person	122	2.5	505	9.0	2.6	- 6.4	-71.1*
	Bus	340	6.9	570	10.1	8.2	- 1.9	-18.8*
		4910		5620				
Banfield Freeway-11	Auto	3161	59.2	3793	54.4	59.4	+ 5.0	+ 9.2
	2 Person	1060	19.8	2034	29.2	20.2	- 9.0	-30.8*
	3+ Person	493	9.2	488	7.0	8.8	+ 1.8	+25.7
	Bus	628	11.8	657	9.4	11.6	+ 2.2	+23.4
		5342		6972				
I-95 Miami-1	Auto	5027	62.0	5170	57.4	61.6	+ 4.2	+ 7.3
	2 Person	2236	27.6	2492	27.7	27.5	- 0.2	- 0.7
	3+ Person	566	7.0	1026	11.4	7.7	- 3.7	-32.5*
	Bus	274	3.4	314	3.5	3.2	- 0.3	- 8.6
		8103		9002				
I-95 Miami-11	Auto	5170	57.4	6080	61.0	55.7	- 5.3	- 8.7
	2 Person	2492	27.7	2714	27.2	29.7	+ 2.5	+ 9.2*
	3+ Person	1026	11.4	821	8.3	11.2	+ 2.9	+34.9
	Bus	314	3.5	352	3.5	3.4	- 0.1	- 2.9
		9002		9967				

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Table 13 (Continued)

COMPARISON OF PIVOT POINT MODEL PREDICTIONS TO ACTUAL MODE SHIFTS
(Using Actual Level-of-Service Changes)

HOV Facility	Mode	Before Period		Actual After Period		Predicted Share-Percent (P)	Absolute Error (P-A)	Relative Error (P-A)/A
		Persons	Share-Percent	Persons	Share-Percent			
			(B)		(A)			
Southeast Exp. (1977) (After: "Phase III")	Auto	4325	42.9	3422	36.1	30.6	+ 2.5	+ 6.9
	2 Person	2358	23.4	1768	18.6	21.3	+ 2.7	+14.5
	3+ Person	1397	13.9	2177	22.9	16.6	- 6.3	-27.5*
	Bus	2000	19.8	2124	22.4	23.5	+ 1.1	+ 4.9*
		10080		9491				
Southeast Exp. (1971)	Auto	6740	75.8	6007	71.0	71.4	+ 0.4	+ 0.6
	Bus	2152	24.2	2454	29.0	28.6	- 0.4	- 1.4*
		8892		8461				
I-495, Lincoln Tunnel	Auto	3718	14.5	4905	15.8	13.0	+ 2.8	+17.7
	Bus	21868	85.5	26092	84.2	87.0	- 2.8	- 3.3*
		25586		30997				

*Indicates mode(s) granted use of HOV lane.

SOURCE: Charles River Associates.

While the Pivot Point Logit Model assumes a fixed number of person trips, the analyst could employ a diversion-type model to assign some number of trips from parallel or competing roadways to the HOV facility, and also consider the use of secular growth factors from historical data to substitute for generated trips. These approaches, however, would significantly add to the computational resources required.

Two types of error measurement are presented in Table 13 -- absolute error and relative error. Absolute error is always smaller than relative error when shares are presented in percentage terms. Also, the absolute error is not as strongly (or inherently) influenced by the size of the base or before mode shares. Conversely, relative error is particularly influenced by the size of the base mode shares. As an extreme example, if before-and-after auto/bus mode shares were 99/1 and 98/2, respectively, and the model forecasted shares of 98.5/1.5, then the absolute modal errors would be +0.5/-0.5, while the relative errors would be +0.51/-50.0. The appropriate measure to use depends on the circumstances being evaluated. For instance, a relative error of 50 percent for the bus mode would likely lead to a situation of serious over-or under-utilization. Conversely, a 50 percent error in the forecast of a 3+ or 4+ carpool mode, given a small mode share to begin with, might not have a measurable impact on travel flow conditions on the corridor being analyzed. However, given a larger base mode share, and conditions such that demand is near capacity, a 50 percent error in carpool mode shares may have a direct influence on travel flow.

For the 12 HOV sites presented in Table 13, absolute errors for mode shares ranged from 0 percent to -9 percent, while relative errors ranged from 0 percent to -72.2 percent. Of course, the errors in person trips or volume of vehicles on the general purpose and HOV lanes would be greater than these error ranges.

Table 13 also indicates which mode or modes were granted use of the priority lanes between the before and after periods. Examination of forecasts for these modes reveals that the model consistently underpredicts the actual mode shares for the priority-granted modes. The average relative error for all carpools granted priority is -28.1%, with a standard deviation of 24.5%. For buses granted priority, the average relative error is -10.3%, with a standard error of 19.5%. Because the predicted mode shares must sum to 1.0, the model overpredicts the mode shares for the nonpriority-granted modes. Since these modes tend to have larger before modal shares, especially for single occupant autos, the relative errors tend to be smaller.

SUMMARY

In summary, the HOV worksheets developed during this study have been shown to provide reasonable forecasts of peak hour travel volumes resulting from the implementation of four types of HOV strategies on freeways. The forecasting procedure is easy to apply and requires only the use of a hand-held calculator. Data requirements are minimal and are comparable to, or even less than, most sketch planning tools currently available.

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect

the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.